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NOLC REPORT 608

1 JULY 1964

EVALUATION OF AIRCRAFT KILL CRITERIA BY
ANALYSIS OF AIRCRAFT ACCIDENT RECORDS (U)

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AUG 27 1964

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ABSTRACT

This report presents results of a study that used records of accidents of U. S. military aircraft in flight to evaluate the aircraft kill criteria used in missile lethality analysis, particularly the criteria employed in optimization of design parameters of fuzes for use with continuous rod warheads. The evaluation consists in comparison of damage sustained by aircraft which were still controllable, or in a very few instances uncontrollable, after the accident, with kill criteria expressed by the designers of each particular type of aircraft. Data for 50 accidents involving tail damage are interpreted, for purposes of fuze-warhead design optimization, as being in agreement, in an average sense, with the designers' kill criteria. Data on damage of wing and nose, though more restricted in variety of accidents, prove that aircraft can in many instances be controlled in flight even though considerable portions of wing or nose have been removed.

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FOREWORD

This study was undertaken for the purpose of assessing the validity of the aircraft kill criteria employed by this Laboratory in fuze design optimization studies for missiles armed with continuous rod warheads. The establishment and validation of such kill criteria are essential to the Laboratory's program of lethality analyses for fuze design optimization.

B. F. HUSTEN
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CONTENTS

	<u>Page</u>
Abstract	Inside front cover
Foreword	i
Acknowledgment	ii
Introduction	1
Summary of Aircraft Damage	1
Comparison of Aircraft Damage and Kill Criteria	5
Discussion of Results.	6
Conclusions	7
Appendixes	
A. Damage Assessment Criteria	8
B. Aircraft Damage Categories	9

ACKNOWLEDGMENT

The accomplishment of these tasks was made possible by the cooperation of the U. S. Naval Aviation Safety Center, Norfolk, Virginia, and the Directorate of Aerospace Safety, Norton Air Force Base, San Bernardino, California, in making available the pertinent records of aviation accidents. The active participation of the personnel of these organizations in this undertaking is gratefully acknowledged.

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INTRODUCTION

In support of its program of fuze development, the U. S. Naval Ordnance Laboratory, Corona (NOLC) is engaged in a continuing series of missile lethality analyses for the purpose of fuze design optimization. The results of such analyses depend in varying degree upon the underlying assumptions and input information. In particular, the decision as to the optimum design of an antiaircraft fuze depends upon the basic assumptions concerning the effectiveness of the warhead lethal agents in destroying or incapacitating the target, which in turn depends upon the assumptions concerning the flight capabilities of damaged aircraft.

To obtain evidence of the ability of damaged aircraft to continue in flight, this Laboratory has examined the records of accidents involving airborne military aircraft on file at the Directorate of Aerospace Safety, San Bernardino, California, and the Naval Aviation Safety Center, Norfolk, Virginia. These records provided photographs and sketches of the damaged aircraft and statements concerning the nature and extent of the damage.

This report describes those accidents that have yielded significant information on vulnerability. In accidents resulting in crashes, the extent of the in-flight damage generally cannot be determined; thus, in the great majority of accidents that contributed useful information, the damaged aircraft was capable of continued flight and was landed at an airfield. This report compares the extent of the damage experienced by such aircraft, and also the amount of damage for the few crashes for which data are available, with the vulnerability criteria that have been set forth by the aircraft designers. The results of this comparison are to be used in determining the areas of enemy aircraft that are vulnerable to continuous rod warheads.

SUMMARY OF AIRCRAFT DAMAGE

Aircraft that sustained significant tail, wing, or nose damage are reported under the heading of the corresponding damage category. Photographs and drawings indicating the extent of damage are presented for the more severely damaged aircraft (Figures 1-29). The methods of calculating the extent of damage are described in Appendix A.

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TAIL DAMAGE

Instances of tail damage are subdivided into (1) damage to the vertical tail section (vertical stabilizer and rudder), (2) damage to the horizontal tail section (horizontal stabilizer and elevator), and (3) cases in which both vertical and horizontal tail sections were damaged.

Vertical Tail Section Damage

All but two of the aircraft listed in Table 1 returned safely to base after sustaining vertical tail section damage in the amount indicated. An A3D lost 68 percent of its rudder and vertical stabilizer (Figure 6) on takeoff from an aircraft carrier; the pilot controlled the aircraft but was forced to abandon it because a safe landing could not be ensured. The other aircraft, a B-47, lost its entire vertical stabilizer, went out of control, and crashed.

TABLE 1. Percentage Loss of Vertical Tail Section

Aircraft	Percentage Loss	Figure No.	Aircraft	Percentage Loss	Figure No.
T-33	40	1, 3A	A4D	10	6
T-33	47	2A	A4D	6	
T-33	40	2B	A3D	68	
F2H	32	3B	A3D	14	
F-86	5		A3D	9	
FJ-3	7		B-66	37	7A 7B
F8U	11		B-47*	100	
F9F-6	78	4	B-52	71	
A4D	40	5	B-52	75	

* Crash.

Horizontal Tail Section Damage

All the aircraft listed in Table 2 returned safely to base after sustaining the damage indicated.

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TABLE 2. Percentage Loss of One Horizontal Stabilizer and Elevator

Aircraft	Percentage Loss	Figure No.	Aircraft	Percentage Loss	Figure No.
T-33	3	9B 8, 9A 10	F9F-6	90	12
T-33	15		F9F-6	75	
F-86	55		F9F-6	64	
F-89	90		F9F-6	48	
F-100	60		F9F-6	16	
F-100	12		F9F-6	10	
FJ-3	32		F9F-6	5	
FJ-3	4		A4D	2	
F8U	65	11	A3D	18	13
F8U	20		B-47	60	
F8U	10		B-47	5	
F8U	5				

Vertical and Horizontal Tail Damage

Four of the aircraft included in Table 3 went out of control and crashed, the rest returned safely to base.

TABLE 3. Percentage Loss of Vertical and One Horizontal Stabilizer

Aircraft	Percentage Loss		Figure No.
	Horizontal (One Stabilizer and Elevator)	Vertical	
T-33	4	3	14, 15
T-33*	100	37	
T-33*	100	100	
FJ-3	4	20	
F9F-6	59	10	
F9F-6	3	11	
A4D*	75	50	
KC-97	55	54	
B-52*	200**	100	

* Crash.

** Both stabilizers and both elevators were lost.

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WING DAMAGE

All but one of the aircraft listed in Table 4 returned safely to base. An F8U lost its outer wing panel and the inboard droop (Figure 20); after a temporary loss of control and altitude the pilot managed to return the aircraft to its original altitude of 20,000 ft. Although this aircraft was controllable, it was abandoned because a safe landing could not be ensured.

There were seven cases of F8U's losing a droop (Figure 21) while airborne; all of these aircraft returned safely to base.

In addition to the accidents listed in Table 4, there were 30 cases of F-4B aircraft losing honeycomb sections of the outer wing panel. Figure 27 shows the part of the aircraft where the damage occurred. Although as much as 50 percent of the outer wing panel was lost in some instances, no aircraft became uncontrollable.

TABLE 4. Percentage Loss of Area of
One Wing

Aircraft	Percentage Loss	Figure No.	Aircraft	Percentage Loss	Figure No.
T-33	17	16, 17A	F8U	38	20
T-33	15	17B	F8U	11.5*	21
F-86	10		F8U	8	
F-100	22	18	F8U	4	
F-100	12		F8U	2	
F-100	11		F9F-6	13	22
F-100	8		F9F-6	12	
F-100	2		F9F-6	8**	
F-101	7		F11F	13	23
F-102	5		A3D	8	24
FJ-3	18	19	A4D	15	25
FJ-3	10		B-47	20	26

*Seven cases.

**Three cases.

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NOSE DAMAGE

There were 10 cases of aircraft losing their radomes, including in some cases part of the enclosed equipment; all aircraft returned safely to base.

In a midair collision an F-84F lost its entire nose section forward of the instrument panel and returned safely to base (Figures 28 and 29).

COMPARISON OF AIRCRAFT DAMAGE AND KILL CRITERIA

Figures 30 through 39 present comparisons of the accident data and the kill criteria as set forth by the aircraft designers. The kill criteria shown in Figures 30, 31, 34, 37, and 38 were obtained from a report on blast vulnerability criteria, published in February 1954 by the Ballistic Research Laboratory, Aberdeen Proving Ground.¹ Those for Figure 35 were obtained from a later report from the same source.² The kill criteria for Figure 36 were obtained directly from the designers. Aircraft designers' kill criteria were not available for the particular aircraft and types of damage represented in Figures 32, 33, and 39; therefore, kill criteria have been derived on the basis of the accident data for these aircraft and the kill criteria for aircraft of similar types. This procedure is justified by the general agreement between accident data and designers' criteria in those cases for which the criteria are available.

In the first eight graphs (Figures 30 through 37) the percentage loss of the vertical tail section is plotted against the percentage loss of the horizontal tail section. On each of these graphs a smooth curve has been drawn between the points on the horizontal and vertical axes defined by the A-kill damage criteria for horizontal and vertical tail sections. (Aircraft damage categories are defined in Appendix B.) Thus, regions of aircraft controllability (no-kill) and uncontrollability (A-kill) have been established by reference to the aircraft designers' kill criteria. It is also possible to classify aircraft damage in terms of the percentage loss of vertical and horizontal tail sections combined.

Figures 38 and 39 indicate the flight capability of aircraft that have sustained wing damage. The kill region of Figure 38 is defined in terms

¹ BRL/APG TN 870, "Blast Vulnerability Criteria for Several Operational Jet-Type Aircraft," February 1954, CONFIDENTIAL.

² BRL/APG TN 930, "Blast Vulnerability Criteria for F-100 and A4D Jet-Type Aircraft," June 1954, CONFIDENTIAL.

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of the loss of the wing tip and adjoining area; Figure 39 includes seven essentially identical accidents involving the loss of the inboard droop only (Figure 21), and one case in which the inboard droop and the entire wing-tip area were removed (Figure 20). Thus, the line in Figure 39 labeled "NOLC A-Kill Limit" may reasonably be applied only to cases in which the 38 percent loss of wing area includes the loss of the inboard droop.

DISCUSSION OF RESULTS

The interpretation of the accident data is clouded by the bias inherent in the method of generation of the data. Aircraft that survive provide quantitative data; those that crash generally do not yield information on the extent of the damage that caused the crash.

Figure 40 is an attempt to indicate the possible effects of this bias on the accident data in order to assist in the interpretation of the records. The performance of the damaged aircraft depends not only on the amount of damage, measured in terms of the loss of aerodynamic surfaces, but also upon the severing of control links, the pilot's mental and emotional reactions, and various kinematic and aerodynamic conditions at the time of the accident. Thus, even the best of kill criteria based on the percentage of major aerodynamic surfaces removed will represent only the center line of a transition region of appreciable width, separating uncontrollable aircraft. This is represented in Figure 40 by the scattering of letters symbolizing crashed (C) and safe returns (R) on both sides of the kill criterion line. If we assume that the crashes are not included in the accident sample, the effect of this bias on the results is seen to depend upon (1) the width of the transition region and (2) the size of the sample. For a narrow transition region a large sample would yield a substantially correct estimate of the boundary position. If the area of transition is wide, as is probably the case, the location of the center line or optimum kill criterion by means of samples as limited in number and range as those obtainable from accident records is at best an approximation. In particular it should be noted that the central or mean position of the boundary lies on the low damage side of potential extreme cases of the most heavily damaged aircraft that returned to base. If sufficient data are available, the boundary should be located by reference to the major trend, rather than to the relatively infrequent extreme.

With this general situation in mind, we may proceed to examine the class of accidents for which we have the greatest number of cases and the most complete set of kill criteria; namely, damage in the tail section. From the graphs, Figures 30 through 37, it is seen that 6 of the 50 aircraft accidents involving the tail section violate the established kill

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criteria, and in each of these violations the aircraft would have been assigned at least an A-kill, yet it returned safely to base. Referring to Figure 40, it is evident that if the transition region is fairly wide, the occurrence of 6 of the 50 safe returns on the crash side of the kill criterion does not necessarily indicate that the criterion is not entirely sound in an average statistical sense involving the entire population of crashes and safe returns. It is possible, of course, that the kill criteria for tail section damage are slightly conservative, in the sense that the aircraft designers may have underestimated the ability of our aircraft to fly when damaged. When applied to the determination of the ability of our weapons to destroy enemy aircraft, however, such kill criteria would be slightly optimistic. As this could lead to underdesign of our weapons, the more prudent course is to interpret the data as being in general agreement with the established kill criteria.

CONCLUSIONS

The accident records summarized in this report provide ample evidence that military aircraft can in many instances be controlled in flight when suddenly and severely damaged in tail, wing, or nose.

The data for 50 instances of damage of the tail section are best interpreted, for purposes of fuze-warhead design optimization, as being in agreement, in an average sense, with the kill criteria expressed by the designers of the various aircraft (Figures 30 through 37).

Data on damage of the wing and nose, though more restricted in variety of accidents, prove that aircraft can be controlled in flight even though considerable portions of the wing or nose have been removed. Until contrary evidence is revealed, the designers' kill criteria for these sections also can reasonably be employed in lethality analyses undertaken for fuze and warhead design purposes.

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Appendix A

DAMAGE ASSESSMENT CRITERIA

Loss of Wing Area

The area of the wing referred to in this study is that of one wing only; i.e., half of the area from wing tip to wing tip, including the control surfaces. Thus, the original area of the wing is determined by projecting the outline of the wing (considered to extend to the vertical plane through the axis of the fuselage) on the plane of the chords, without deduction for those areas enclosed by the fuselage and nacelles. The boundaries of the part of the wing area which is enclosed within the fuselage and nacelles are determined by rectilinear extension of the leading and trailing edges of the wing.

Wing area remaining after damage is determined from the accident reports, as interpreted by reference to handbooks of structural repair. The reports describe the damage to the aircraft, noting the stations of the extremities of the structure still intact. The structural repair handbooks aid in the location of the damaged structures. The area of the remaining wing structure is determined in the same manner as that of the original wing.

Horizontal Stabilizer

The procedure for assessing damage to a horizontal stabilizer or stabilator is identical with that used for wing damage. The area of the horizontal stabilizer includes the area of the elevator.

Vertical Stabilizer

Unless otherwise stated, the area of the vertical stabilizer is measured by projecting the outline of the stabilizer on the plane of symmetry of the aircraft. For aircraft such as the F9F-6, whose vertical stabilizer is faired into the fuselage in such a way as to make distinction between fuselage and stabilizer difficult, the areas outlined in the structural repair handbooks were employed.

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Appendix B

AIRCRAFT DAMAGE CATEGORIES

The following definitions of aircraft damage categories were agreed upon by U. K. and U. S. representatives during the visit of the A. A. Le-
thality Mission to the U. S. in 1956.³

KK (within A, K)	The aircraft will disintegrate immediately.
K (within A)	The aircraft will fall out of control within 15 sec of the damaging strike.
A (A-kill)	The aircraft will fall out of control within 5 min of the damaging strike.
B	The aircraft will fail to return to base as a result of the damage inflicted. (Sometimes B damage may be associated with a specific time after attack; e.g., B4 indicates within 4 hr of the attack.)
C	The object of the mission will not be achieved.
E	The aircraft will be structurally damaged on landing, necessitating repairs before further flight.

³RAE TN ME 347, "The Assessment of the Vulnerability of Soviet Aircraft to Continuous Rod Attack," January 1962, SECRET.

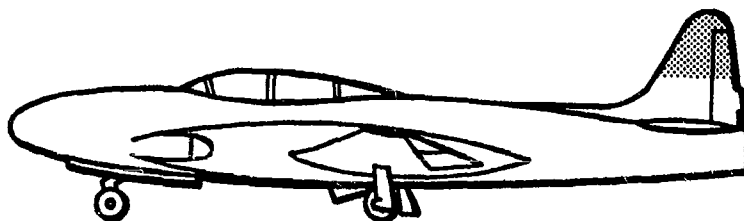
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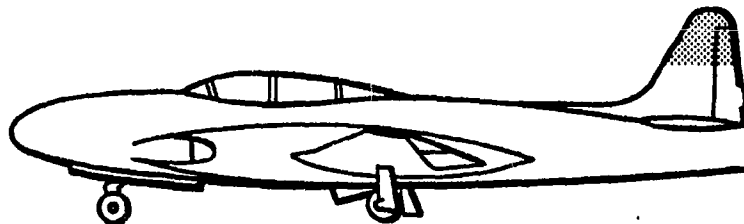
FIGURE 1. T-33 With Top of Stabilizer and Entire Rudder Missing

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A. T-33 WITH 47% OF VERTICAL TAIL SECTION MISSING

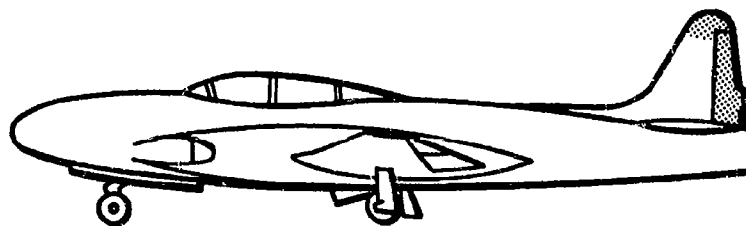


B. T-33 WITH 40% OF VERTICAL TAIL SECTION MISSING

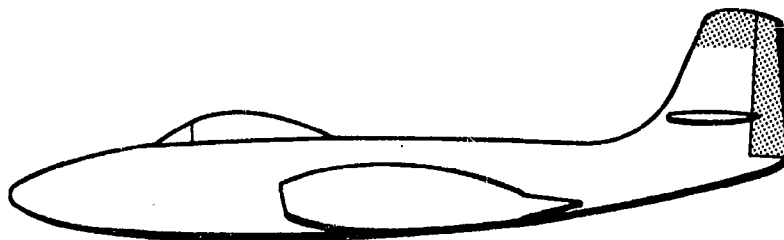
**FIGURE 2. T-33 Aircraft With Similar Vertical Tail
Section Damage**

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A. T-33 WITH 40% OF VERTICAL TAIL SECTION MISSING



B. F2H WITH 32% OF VERTICAL TAIL SECTION MISSING

FIGURE 3. Two Aircraft With Vertical Stabilizers
Damaged and Rudders Missing

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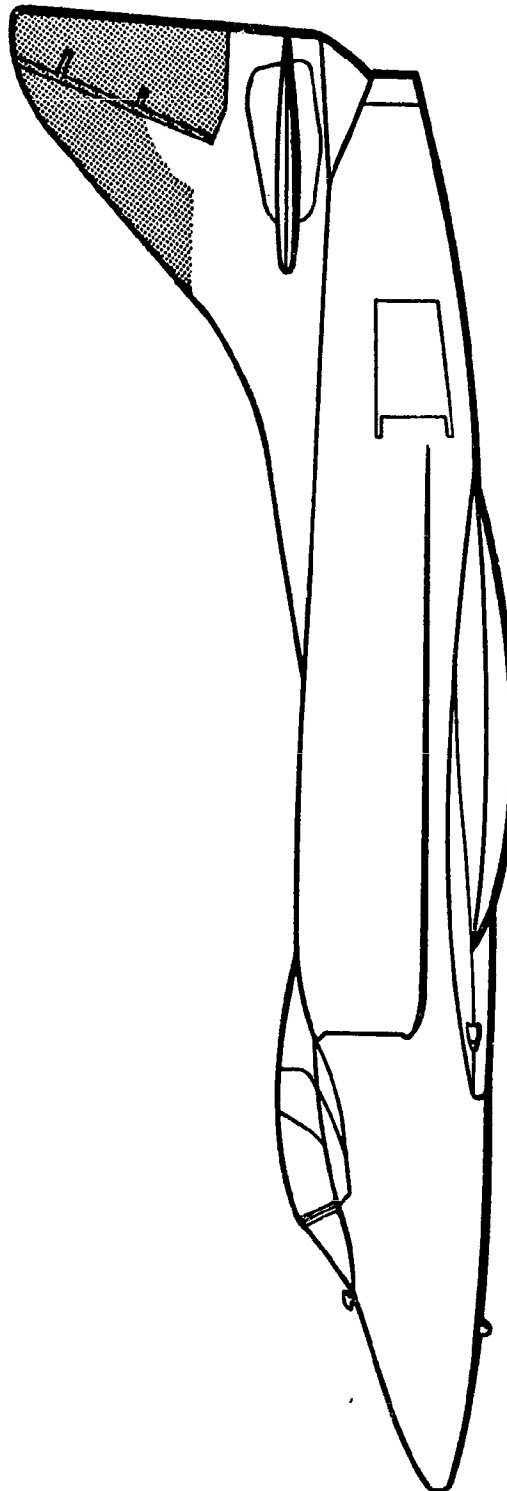
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FIGURE 4. F9F-6 With the Top Rudder and Vertical Fin Missing

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**FIGURE 5. A4D With the Entire Rudder and Top of Stabilizer Missing
(40% of Vertical Tail Section Lost)**

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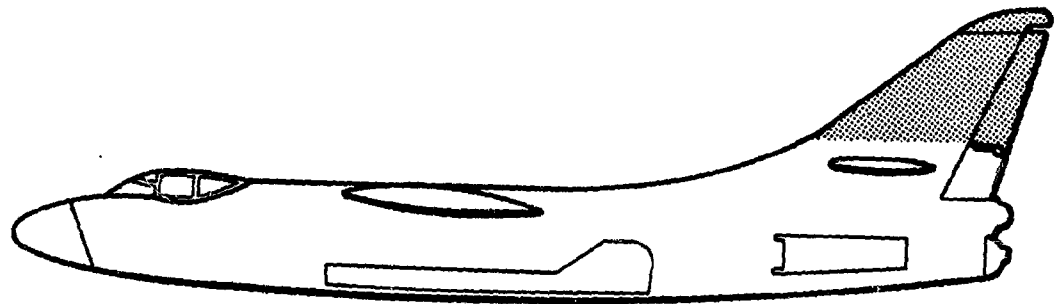
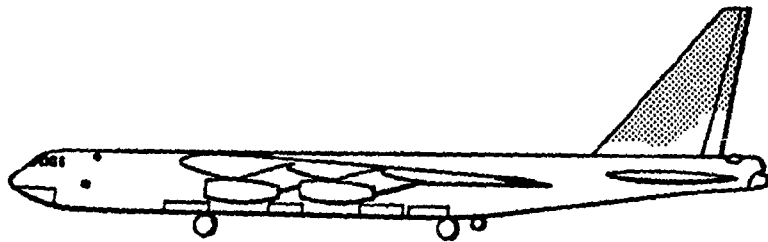
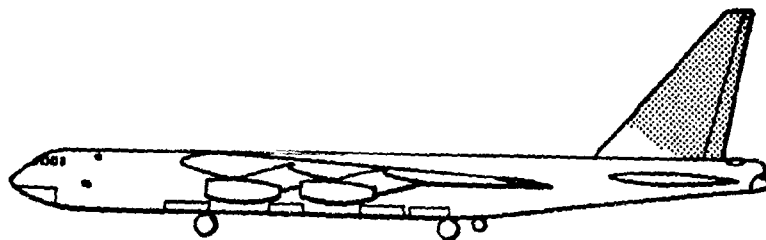


FIGURE 6. A3D With 68% of Vertical Tail Section Lost



A. AIRCRAFT LOST 71% OF STABILIZER AND RUDDER



B. AIRCRAFT LOST 75% OF STABILIZER AND RUDDER

FIGURE 7. B-52 Aircraft With Vertical Tail Sections Damaged

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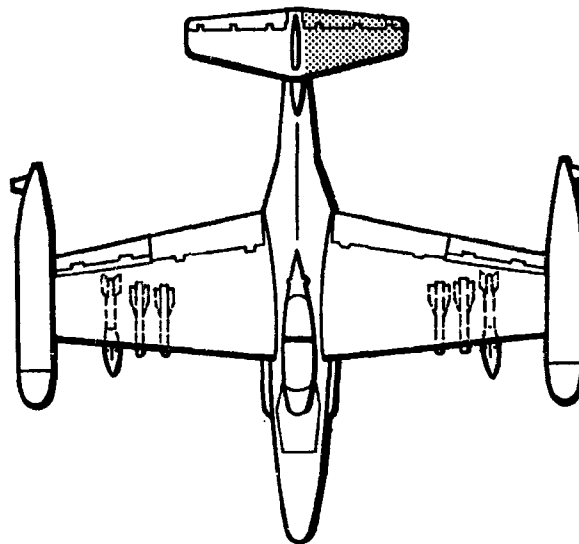
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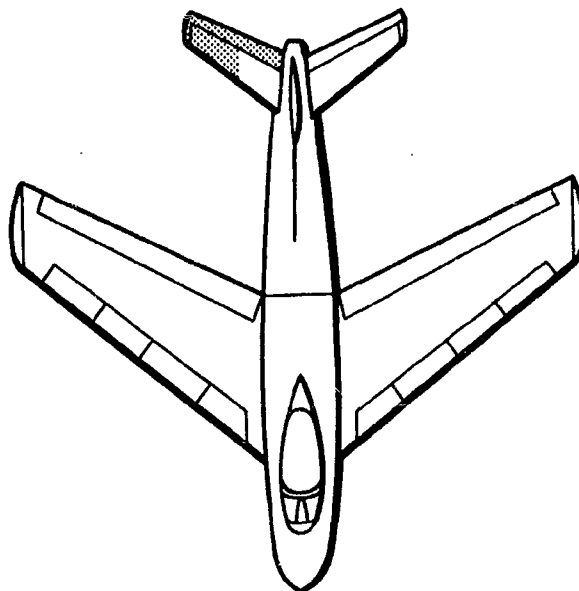
FIGURE 8. F-89 With 90% of Left Horizontal Stabilizer and Elevator Missing

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A. F-89 WITH 90% OF LEFT STABILIZER LOST



B. F-86 WITH 55% OF STABILIZER AND ELEVATOR LOST

FIGURE 9. Two Aircraft With Horizontal Tail Damage

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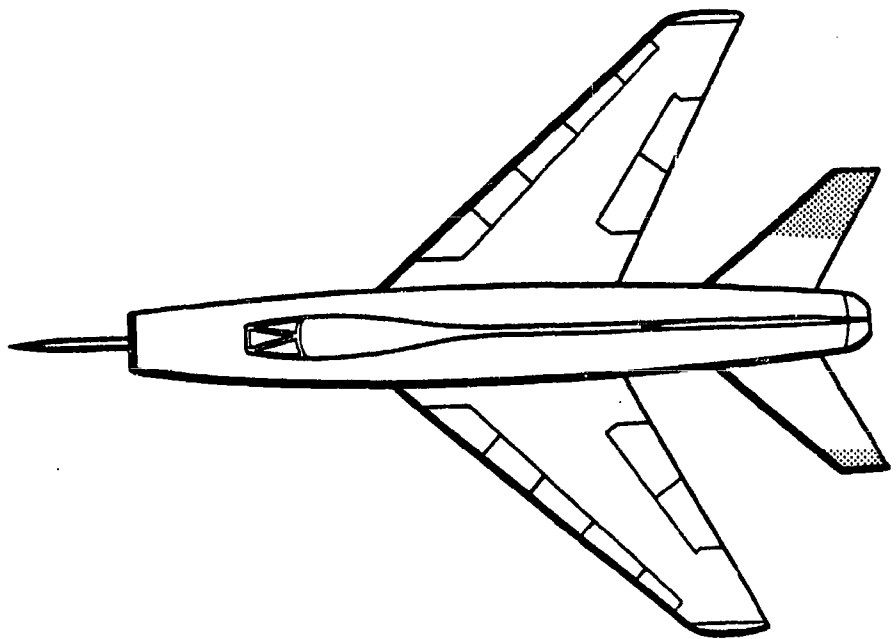


FIGURE 10. F-100 With 44% of the Right and 16% of Left Stabilizers Missing

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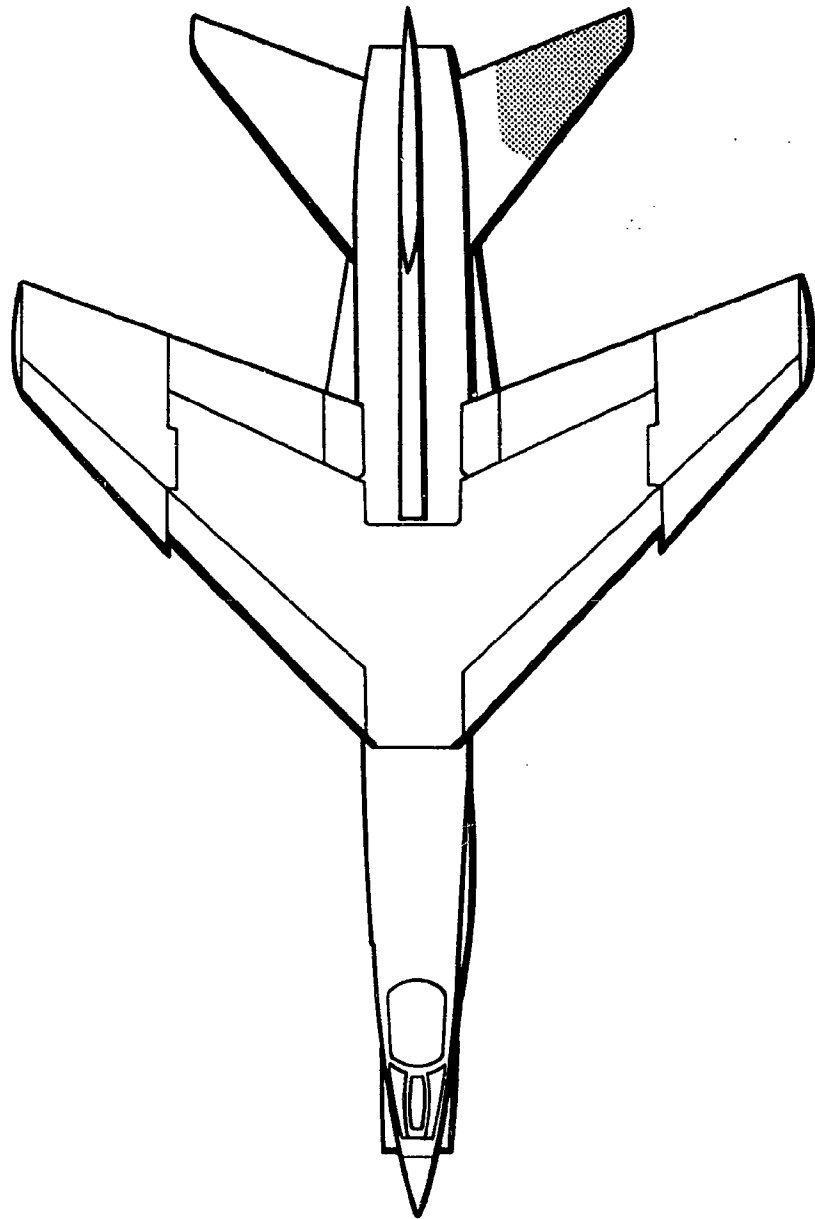


FIGURE 11. F8U With 65% of Stabilizer Lost

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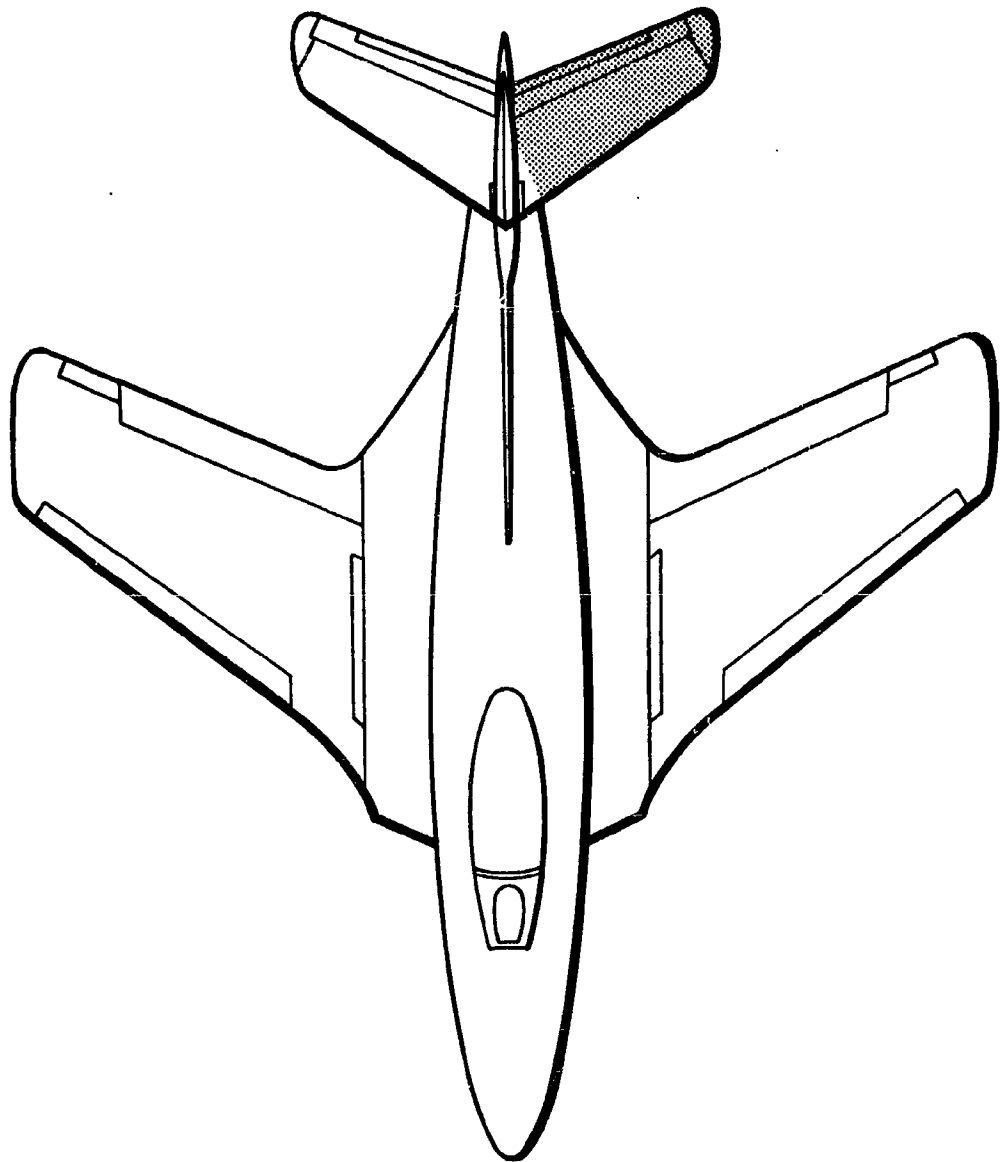


FIGURE 12. F9F-6 With 90% of Stabilizer and Elevator Missing

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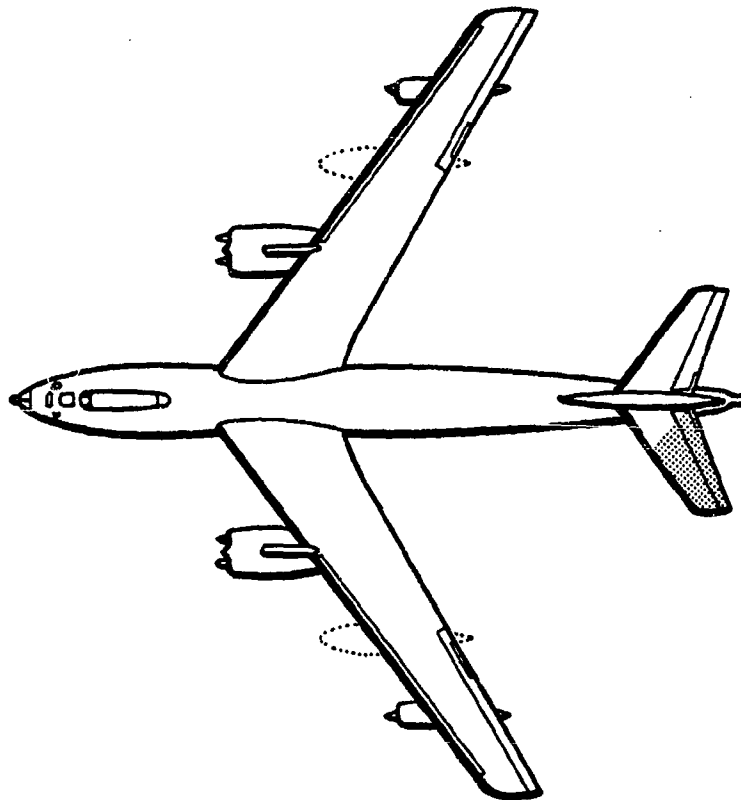


FIGURE 13. B-47 With 60% of Left Horizontal Stabilizer and Elevator Missing

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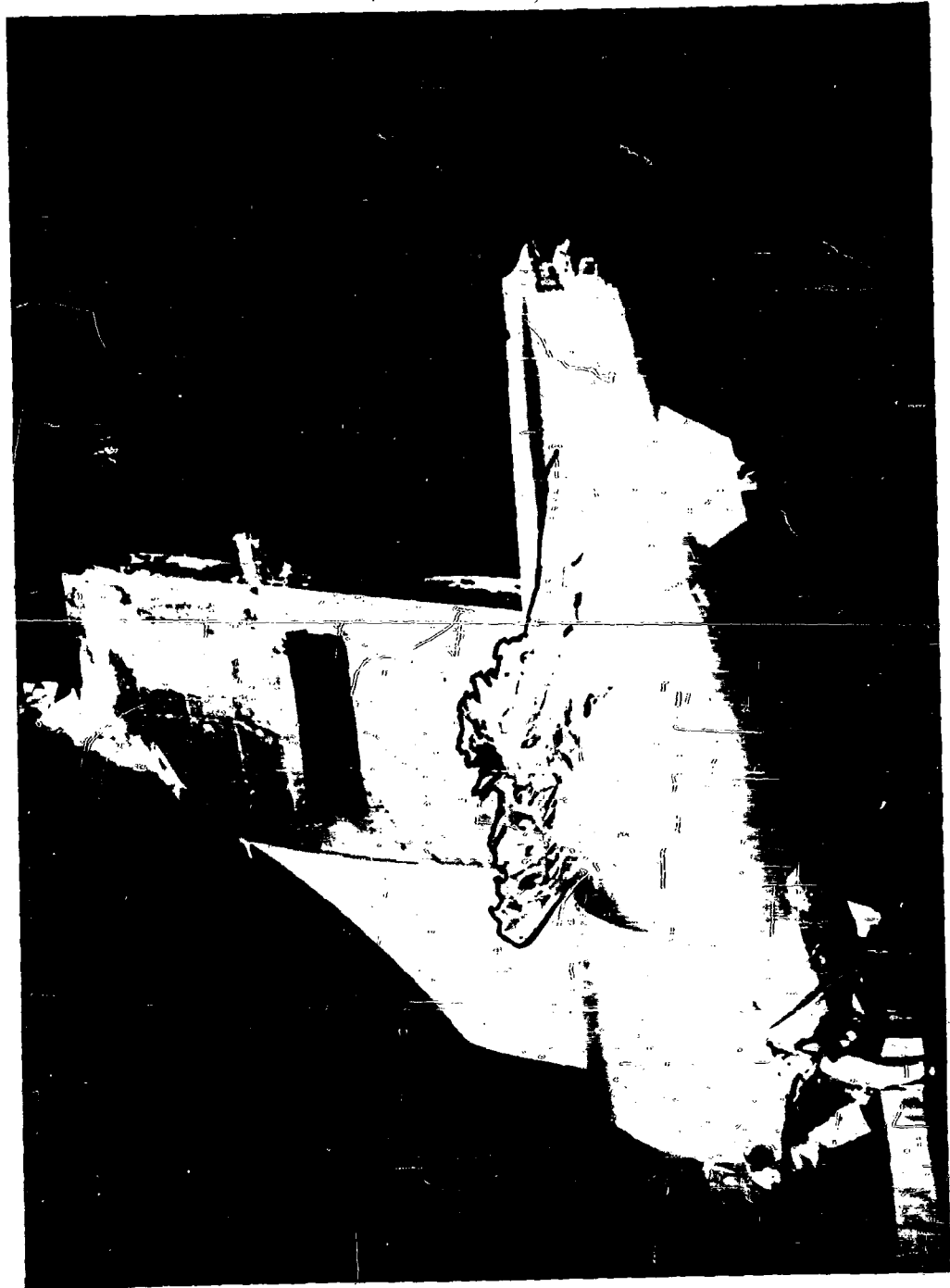
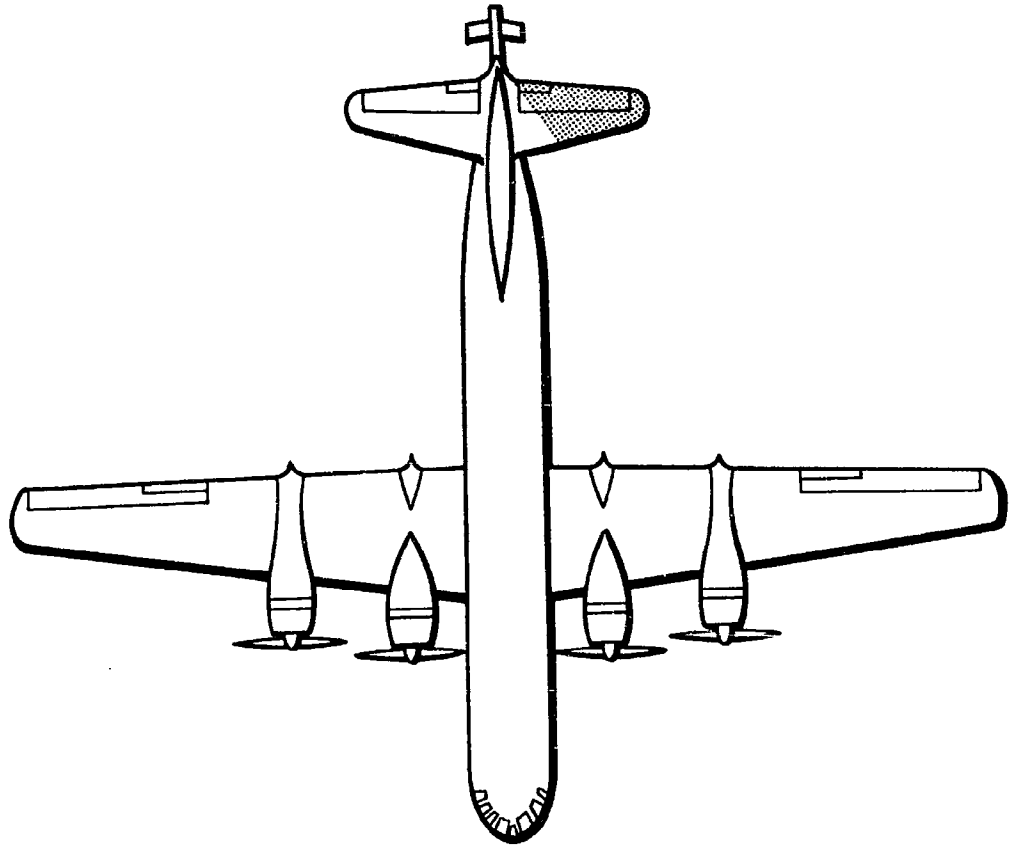


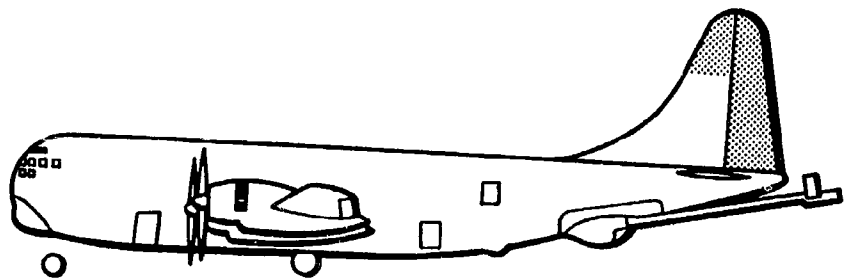
FIGURE 14. KC-97 With 54% of Vertical Tail Surface and 55% of One Horizontal Stabilizer and Elevator Removed

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A. TOP VIEW SHOWING 55% OF LEFT HORIZONTAL STABILIZER
AND ELEVATOR MISSING



B. SIDE VIEW SHOWING 54% OF VERTICAL TAIL SECTION REMOVED

FIGURE 15. KC-97 With Tail Section Damaged

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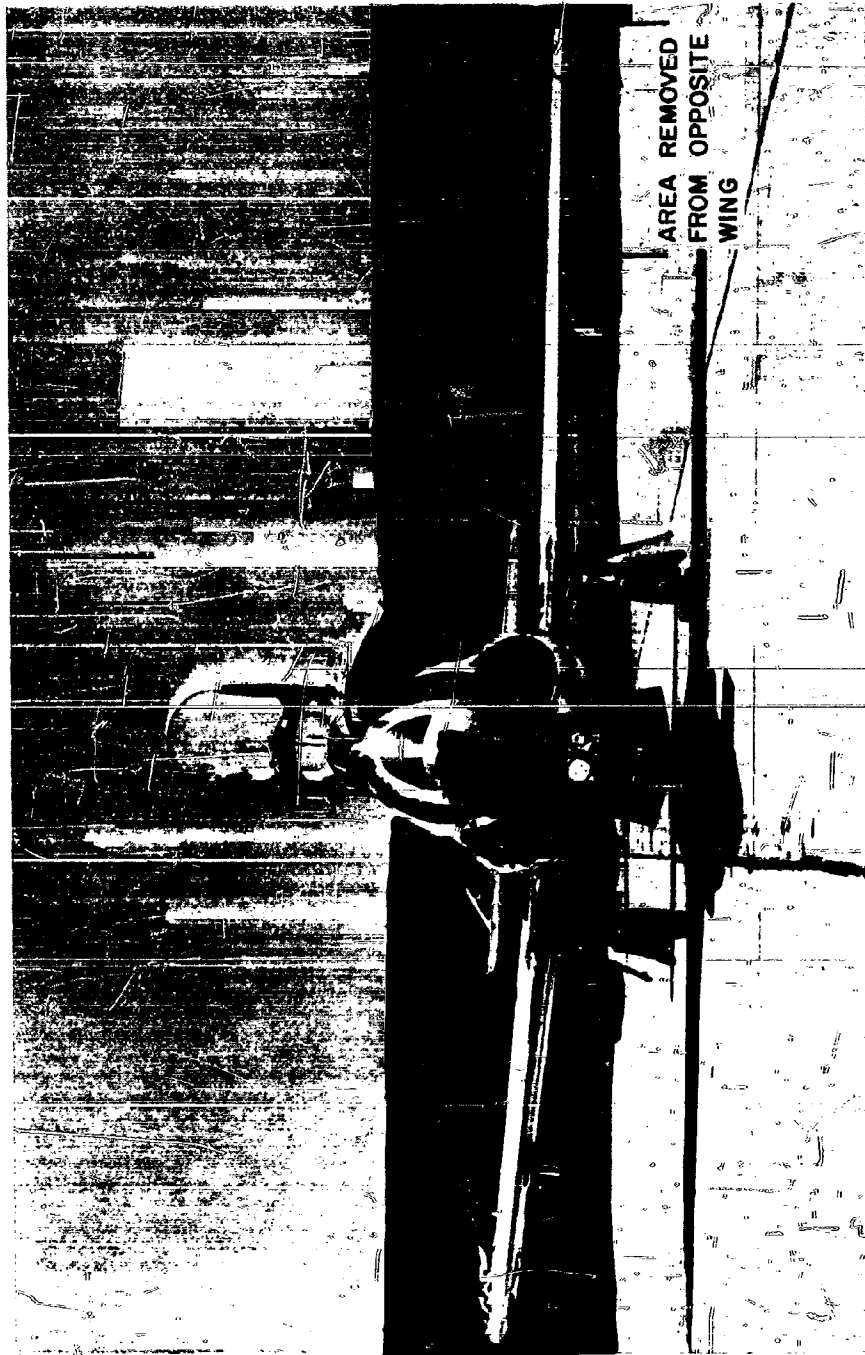
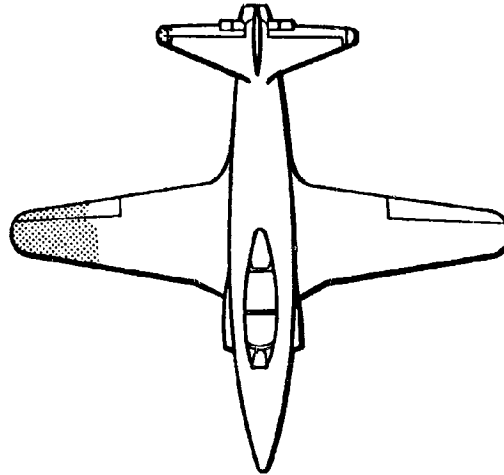


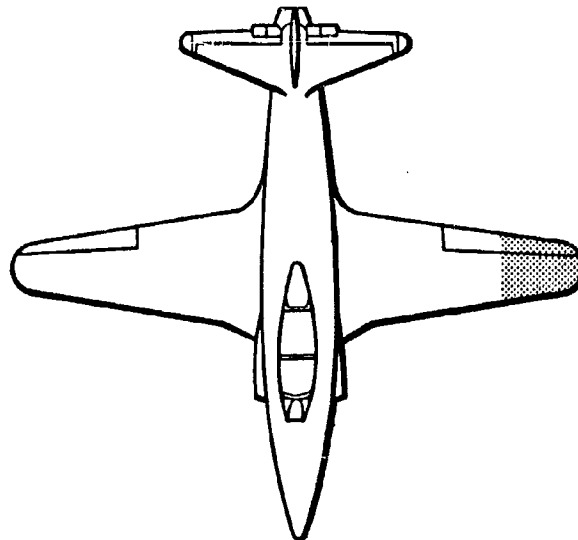
FIGURE 16. T-33 With 17% of Right Wing and Tip of Right Horizontal Stabilizer Removed

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A. 17% OF RIGHT WING AND RIGHT HORIZONTAL
STABILIZER TIP REMOVED



B. 15% OF LEFT WING REMOVED

FIGURE 17. T-33 Wing Damage

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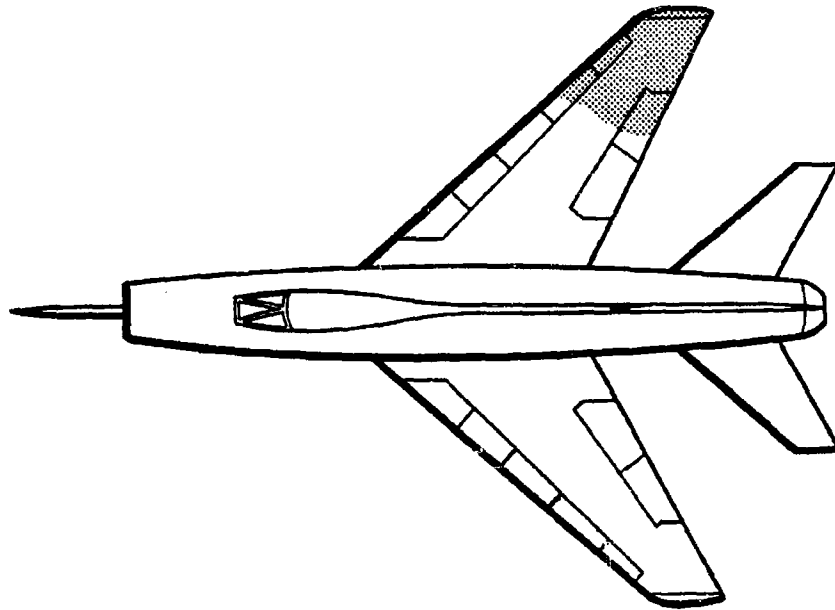


FIGURE 18. F-100 With 22% of Right Wing Removed

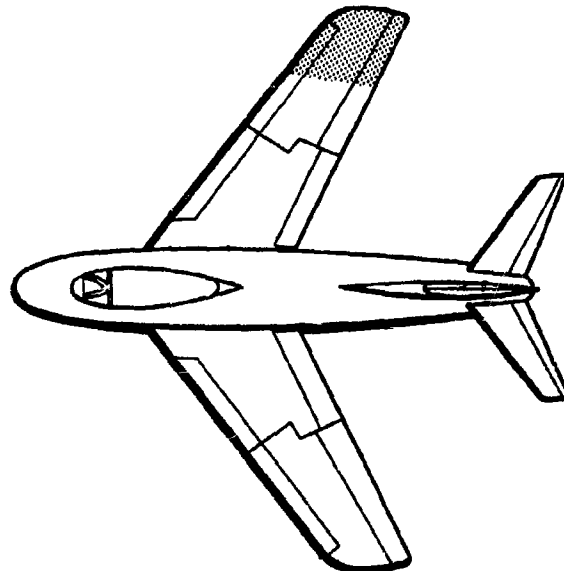


FIGURE 19. FJ-3 With 18% of Right Wing Removed

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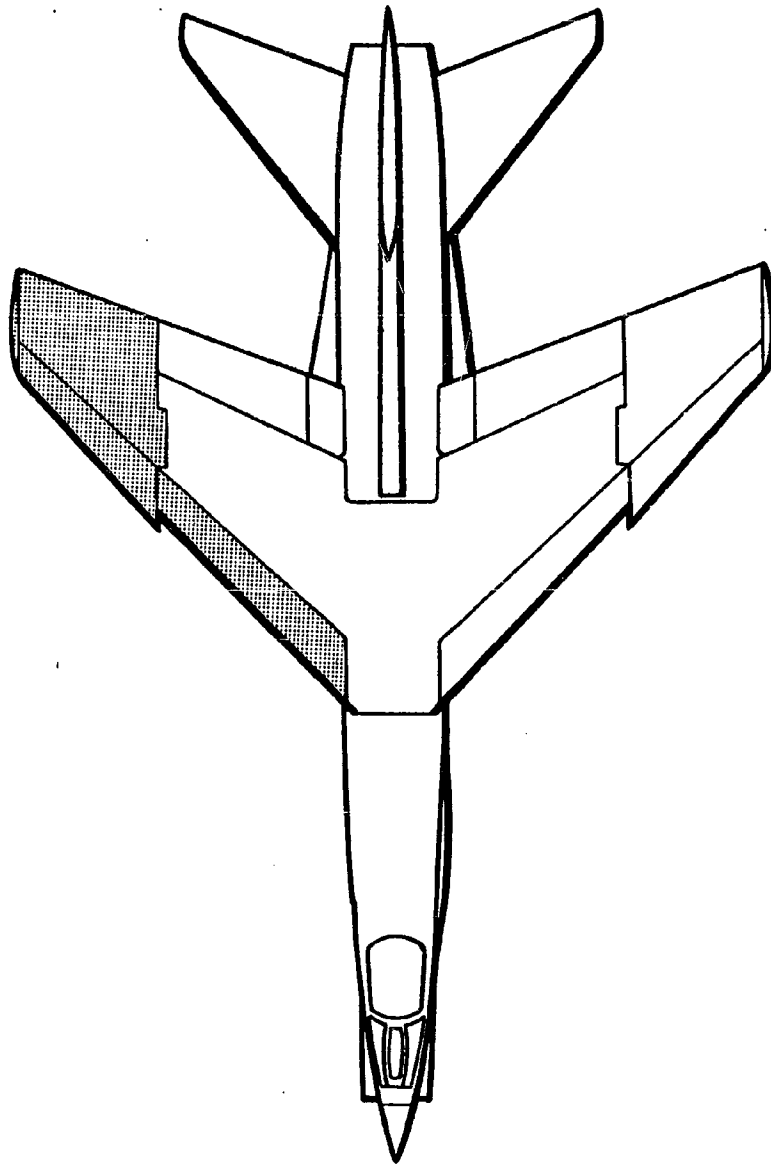


FIGURE 20. F8U With 38% of Right Wing Removed

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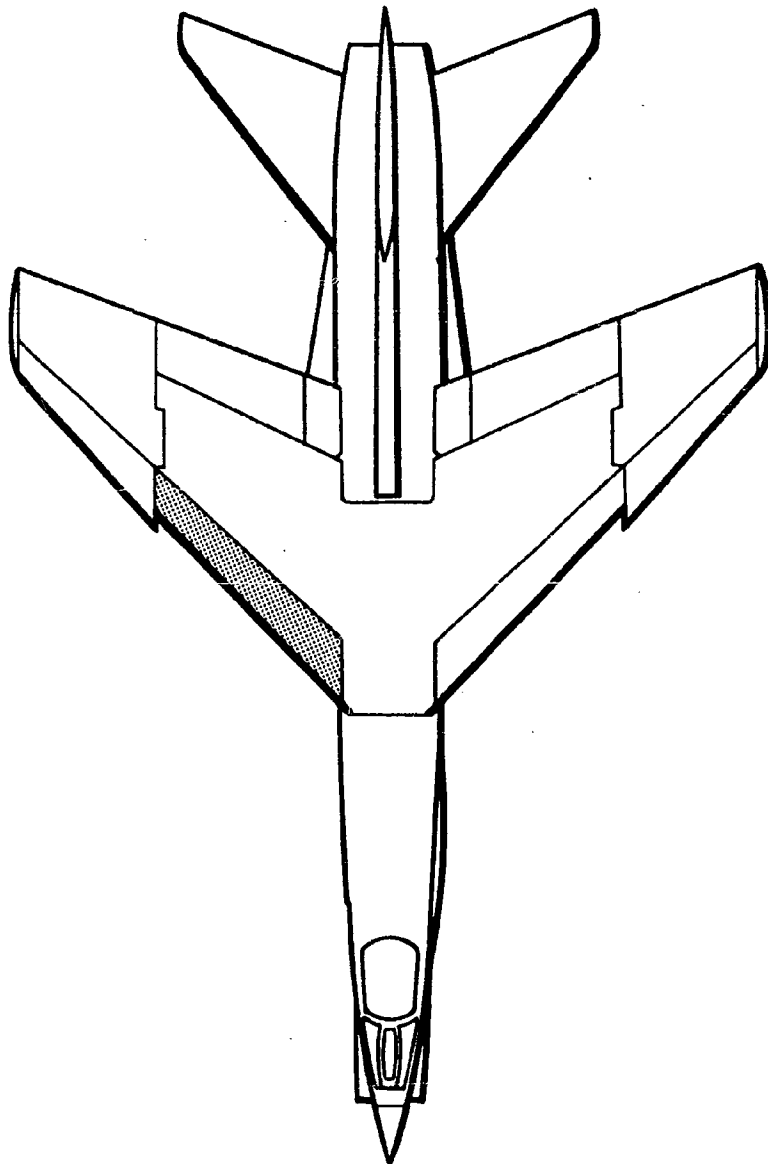


FIGURE 21. F8U With Right Inboard Droop Missing (11.5% of Wing Area)

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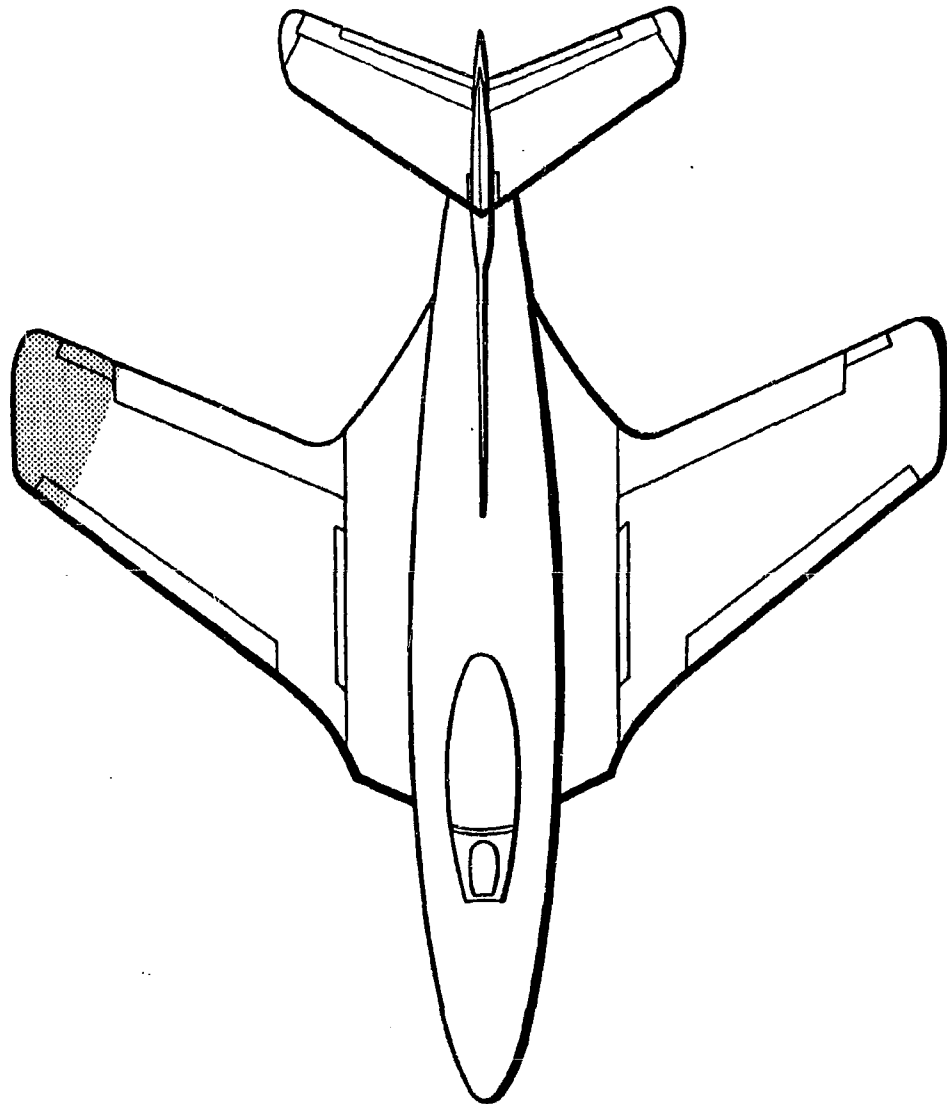


FIGURE 22. F9F-6 With 13% of Right Wing Removed

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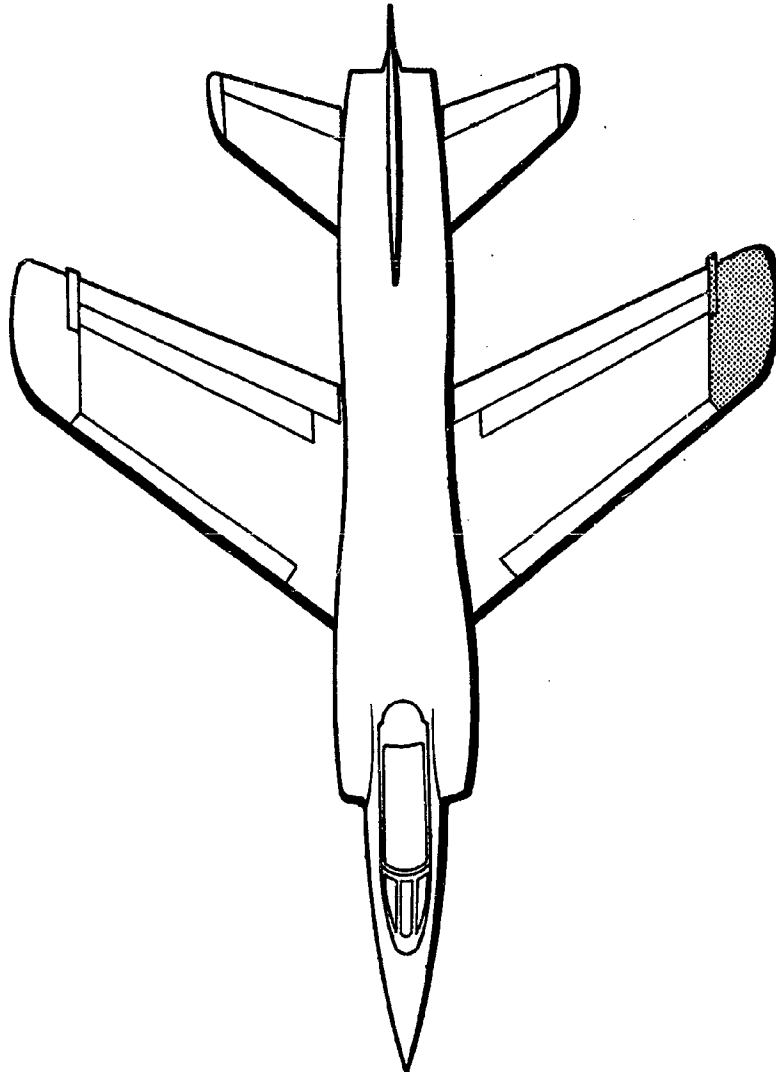


FIGURE 23. F11F With 13% of Left Wing Missing

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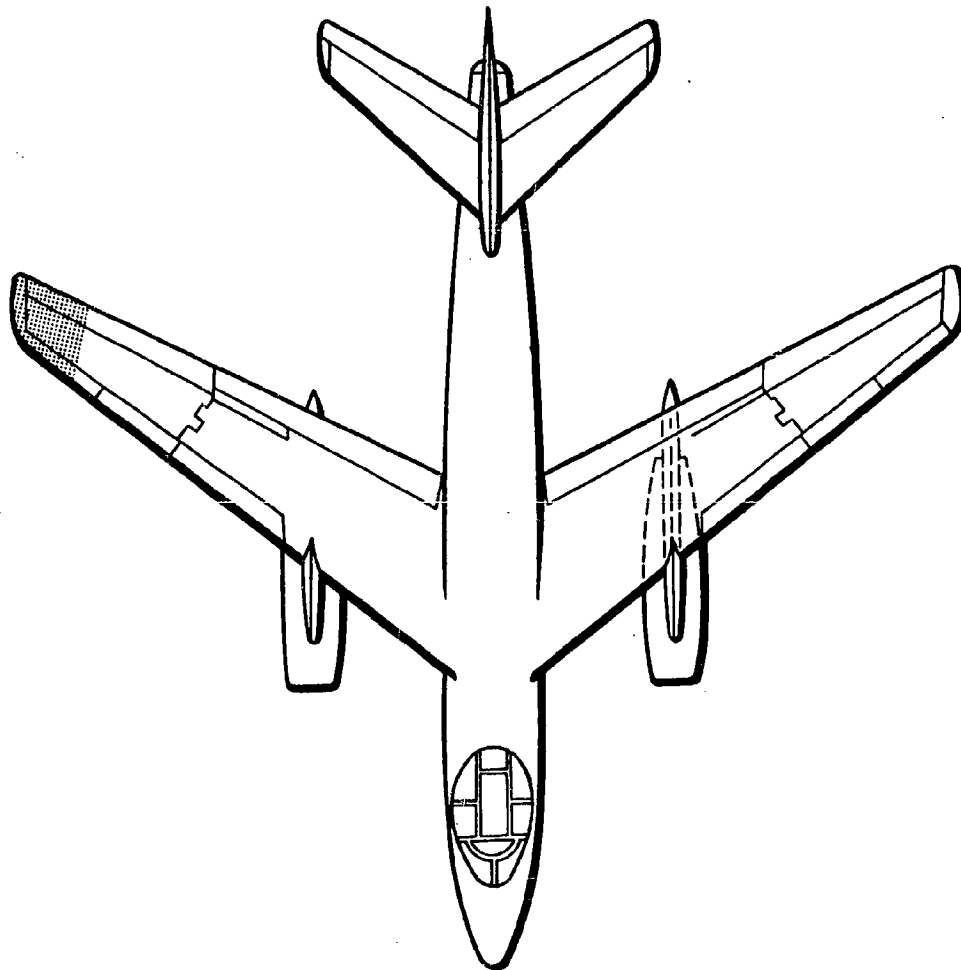


FIGURE 24. A3D With 8% of Right Wing Missing

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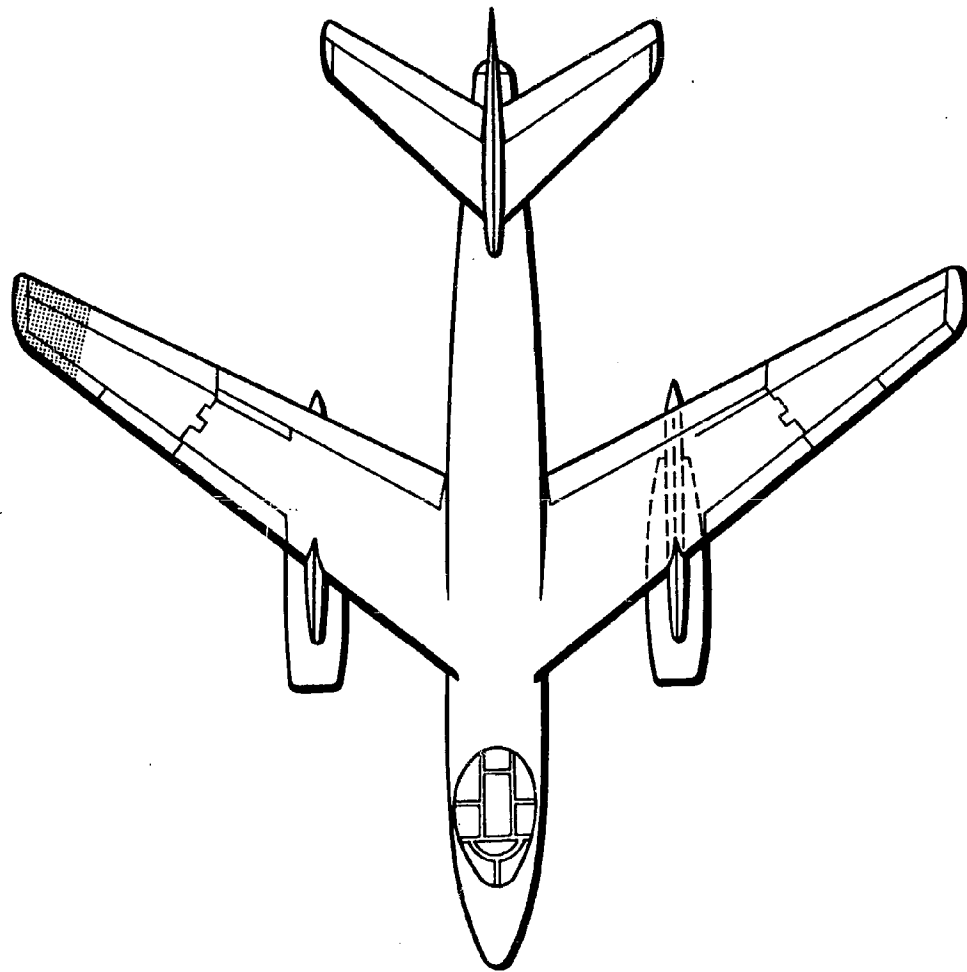


FIGURE 24. A3D With 8% of Right Wing Missing

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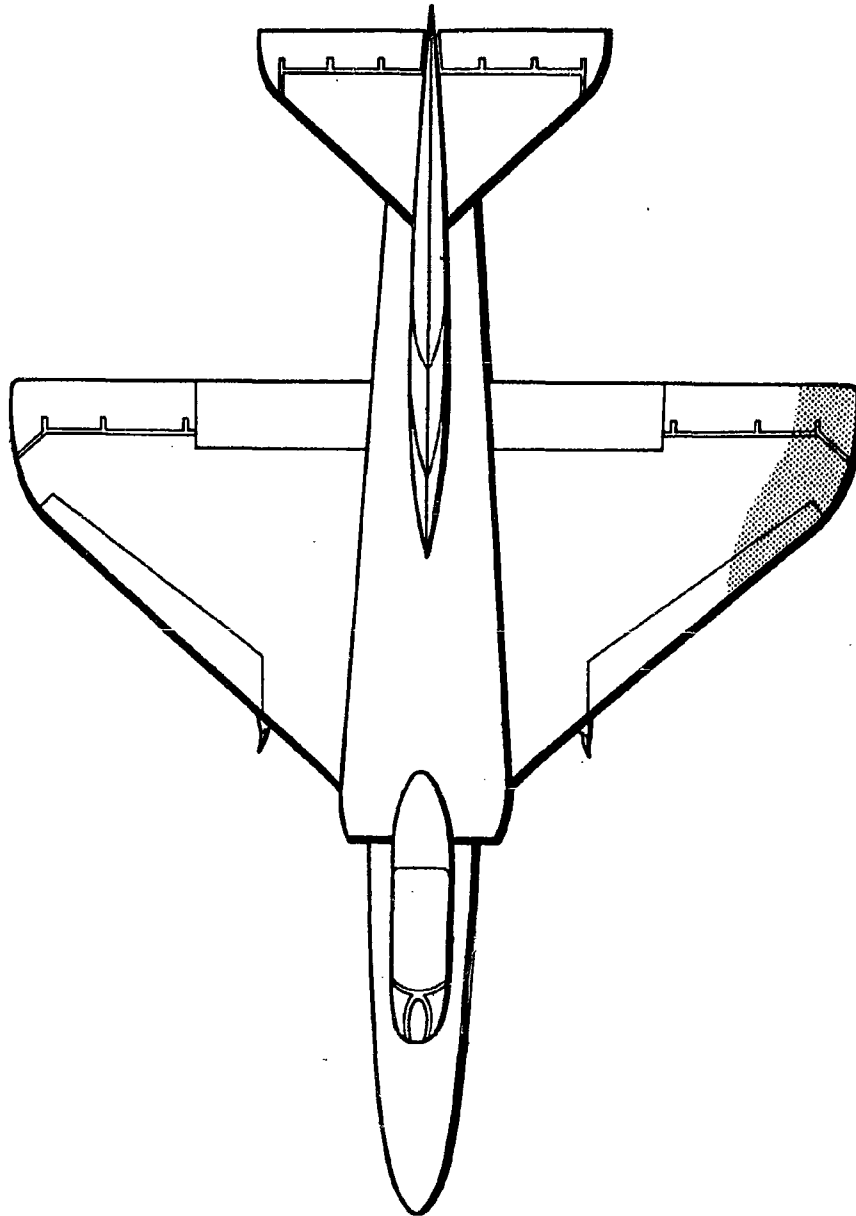


FIGURE 25. A4D With 15% of Left Wing Removed

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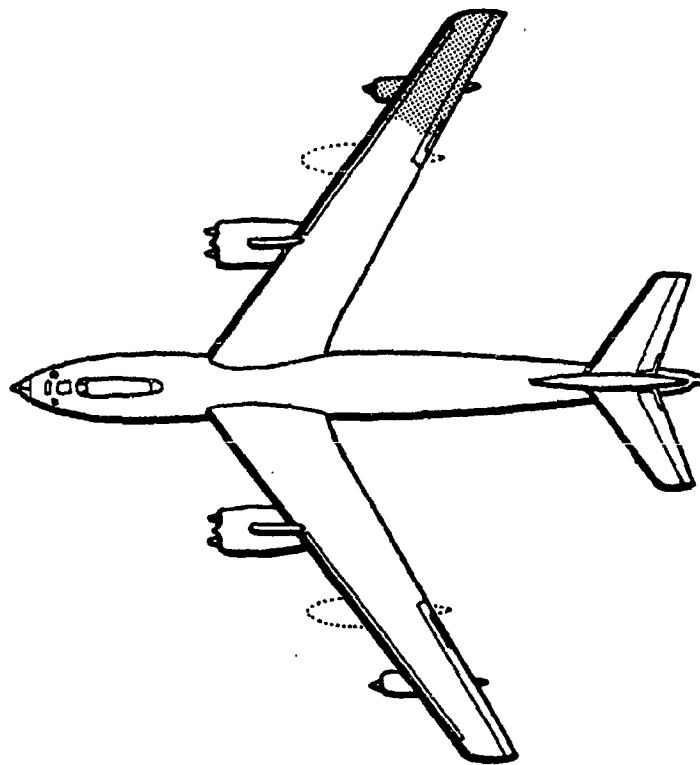


FIGURE 26. B-47 With 20% of Right Wing Missing, Including Outboard Engine

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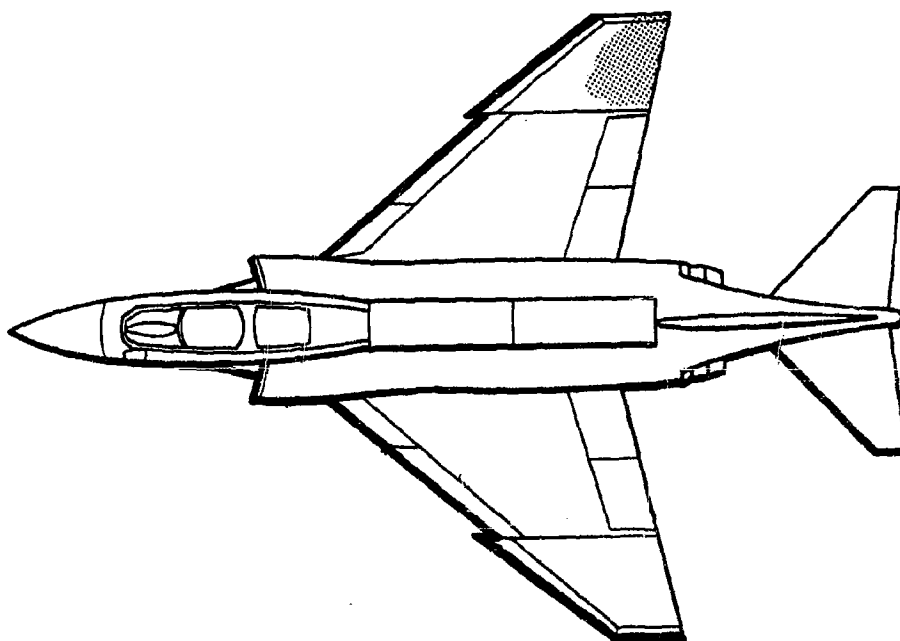


FIGURE 27. F-4B With 50% of Outer Wing Panel Removed

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FIGURE 28. F-84F With Nose Section Removed

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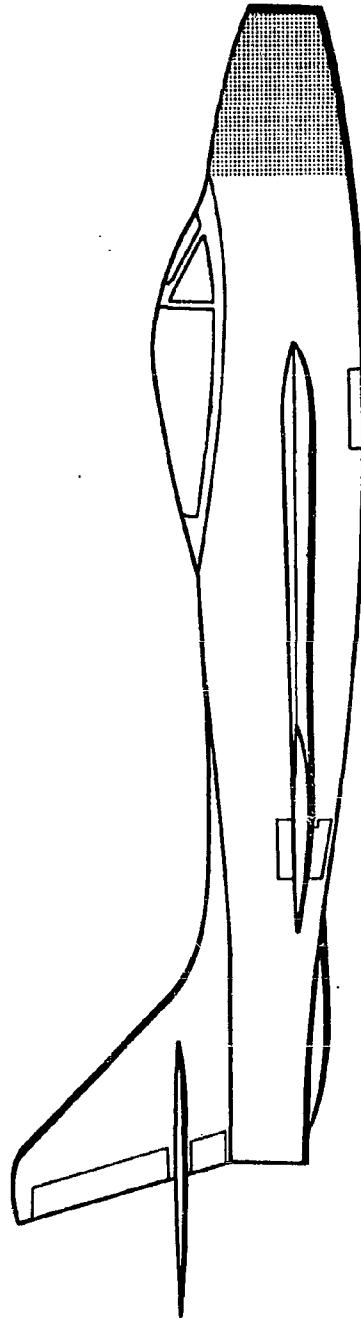


FIGURE 29. F-84F Nose Damage

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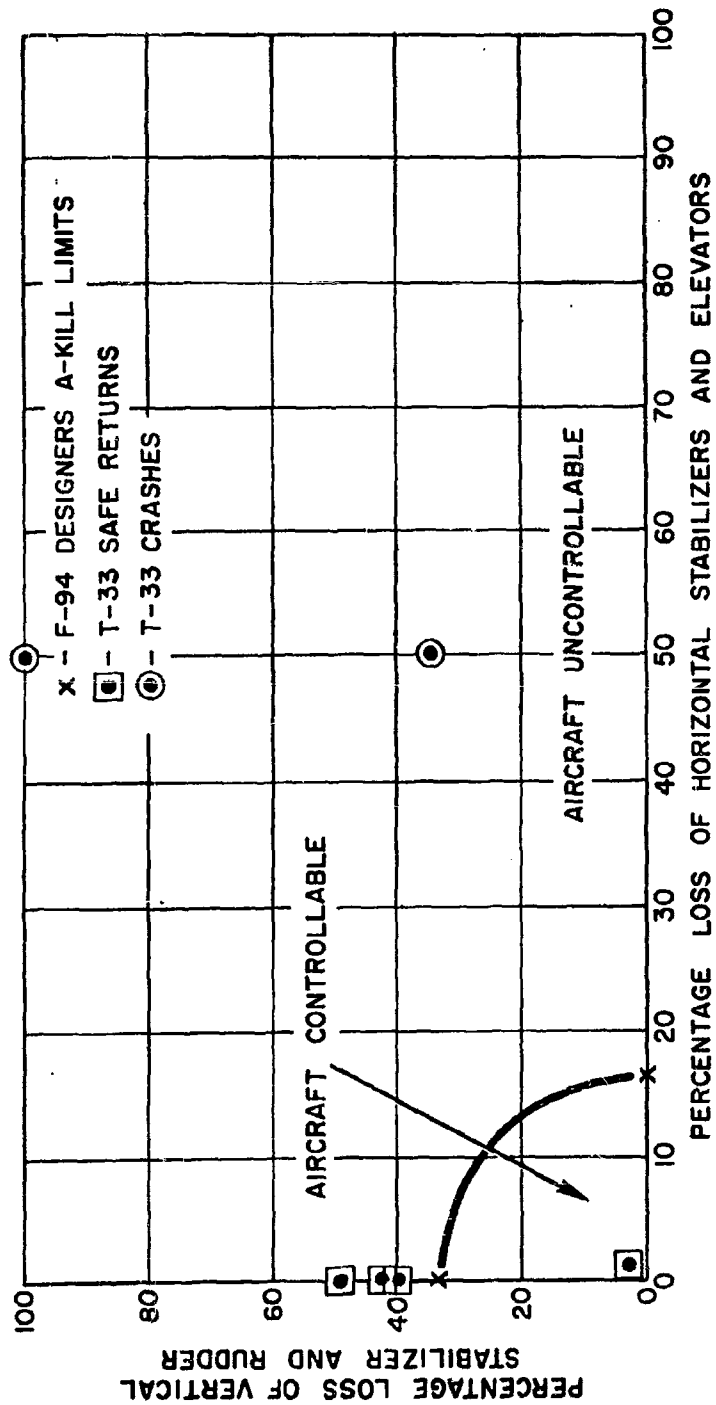


FIGURE 30. Flight Capability of T-33 Damaged in Tail Section

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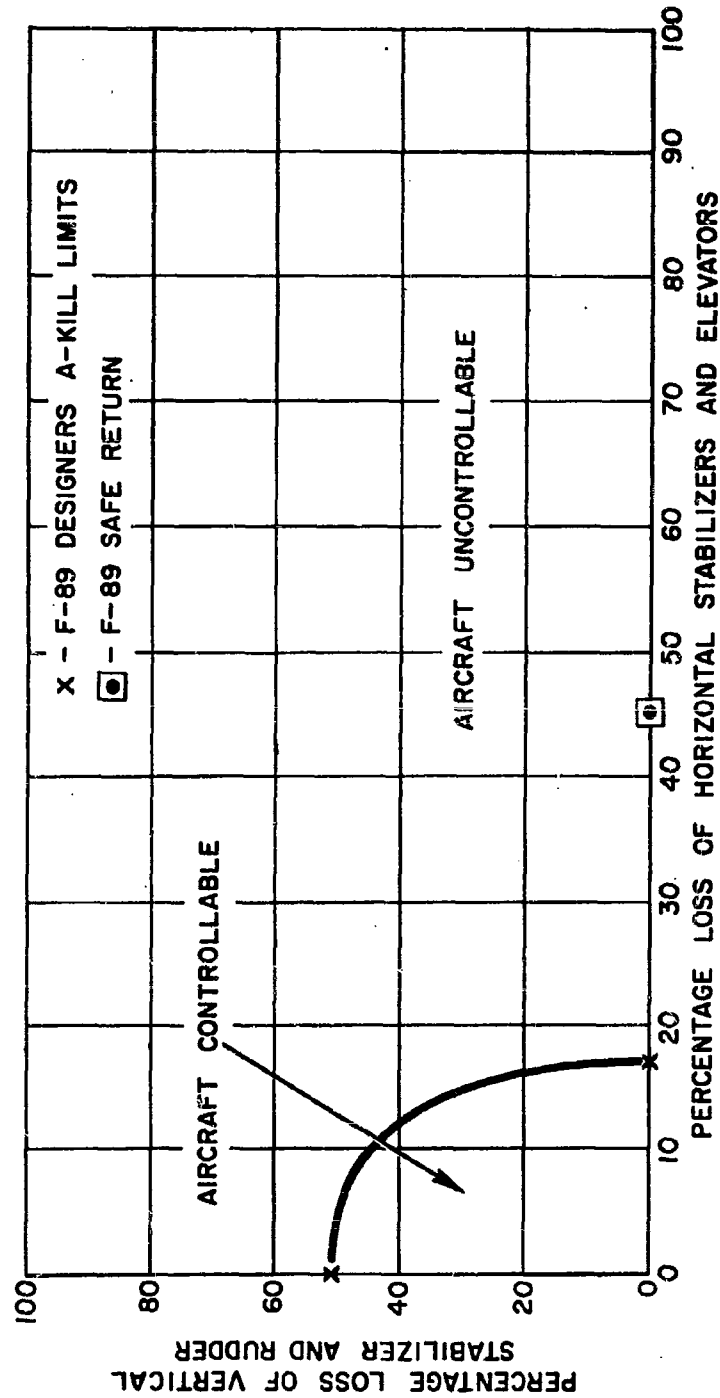


FIGURE 31. Flight Capability of F-89 Damaged in Tail Section

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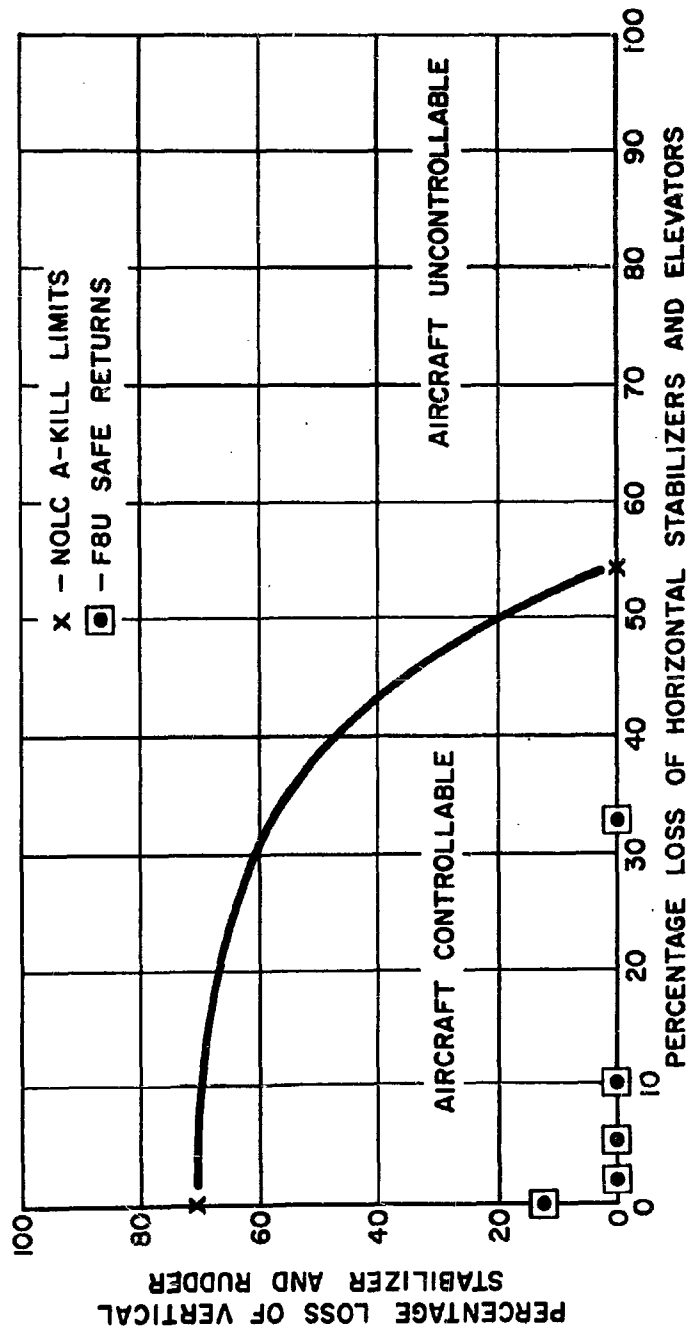


FIGURE 32. Flight Capability of F8U Damaged in Tail Section

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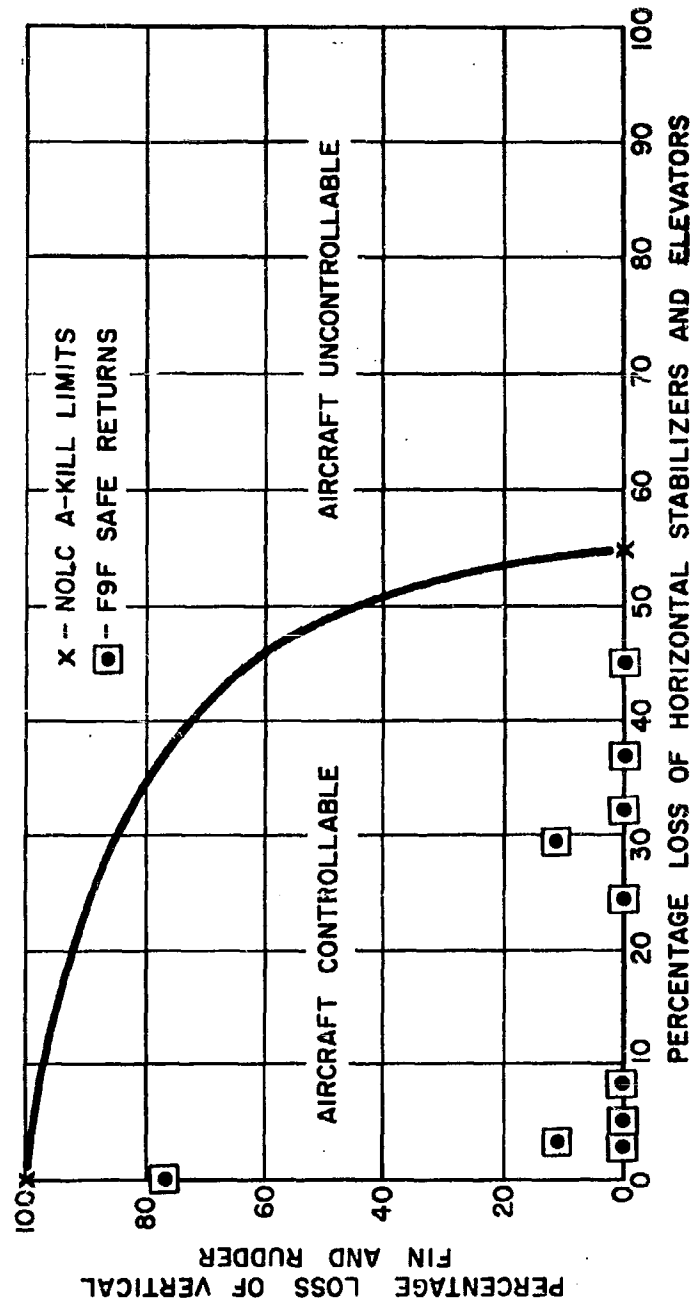


FIGURE 33. Flight Capability of F9F Damaged in Tail Section

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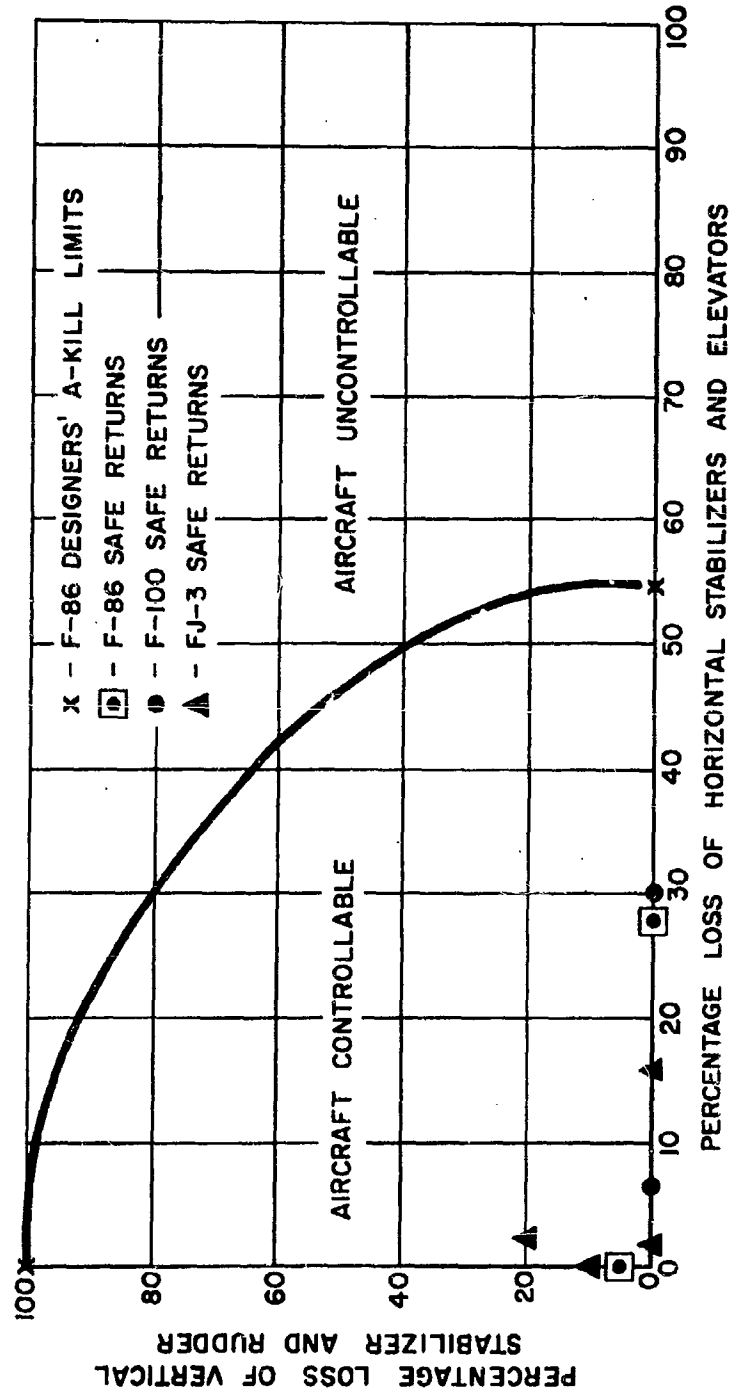


FIGURE 34. Flight Capability of F-86, F-100, FJ-3 Damaged in Tail Section

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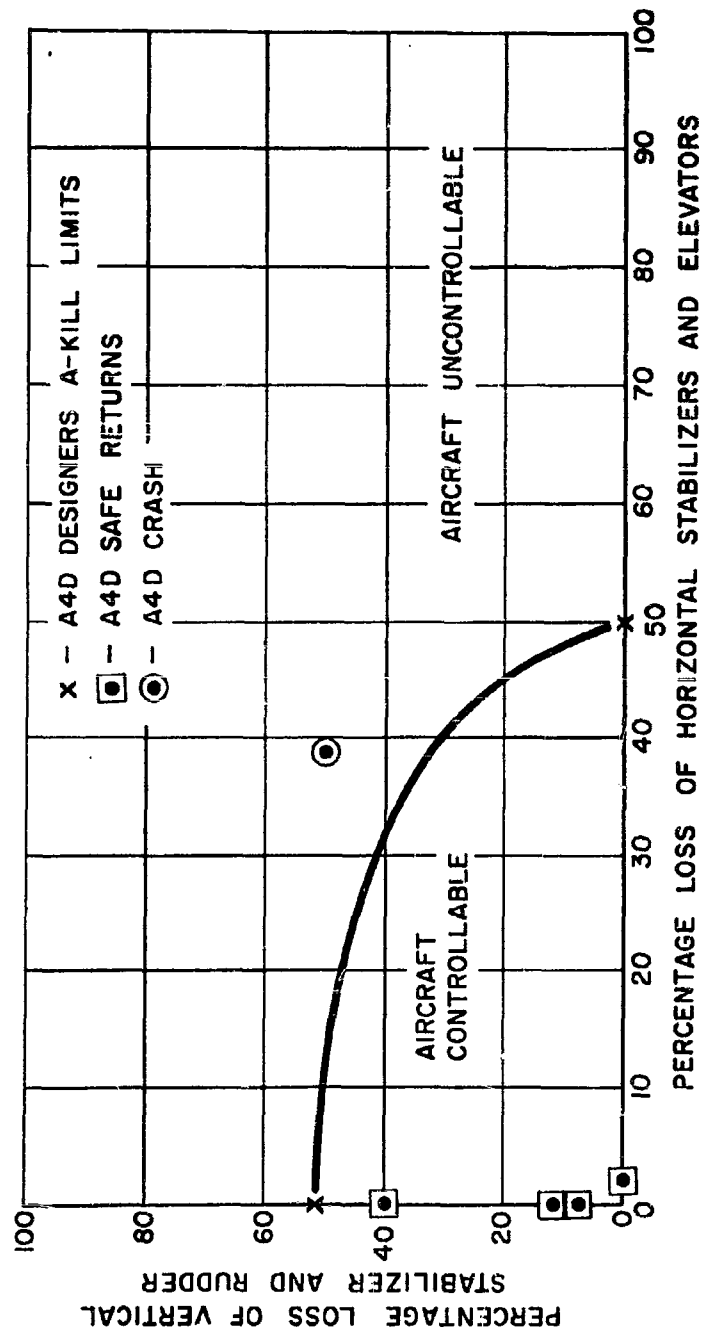


FIGURE 35. Flight Capability of A4D Damaged in Tail Section

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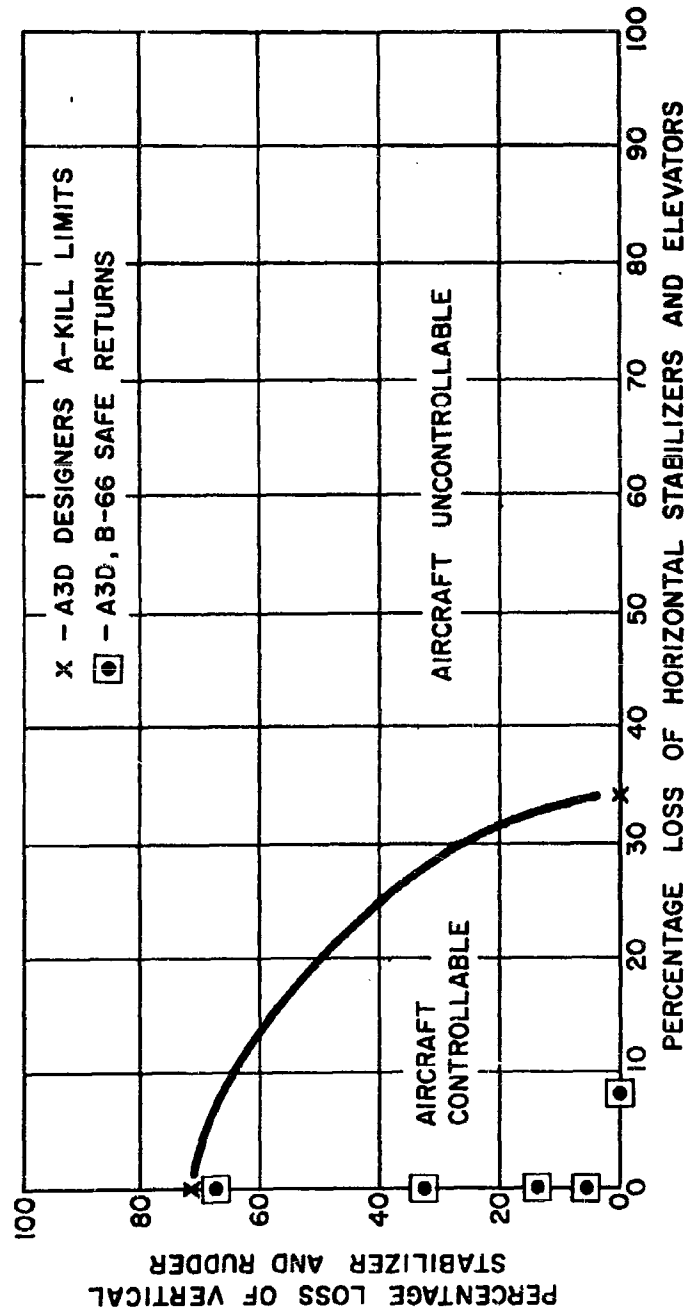


FIGURE 36. Flight Capability of A3D, B-66 Damaged in Tail Section

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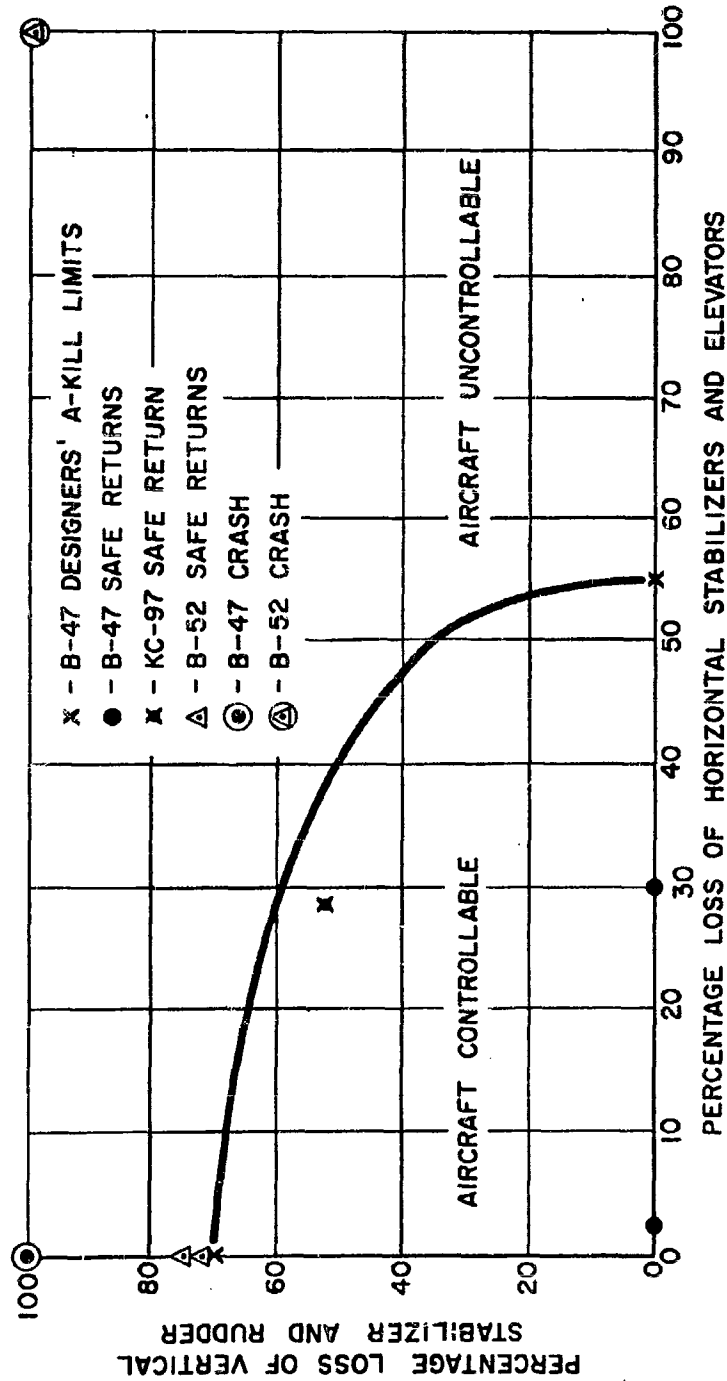


FIGURE 37. Flight Capability of Heavy Aircraft Damaged in Tail Section

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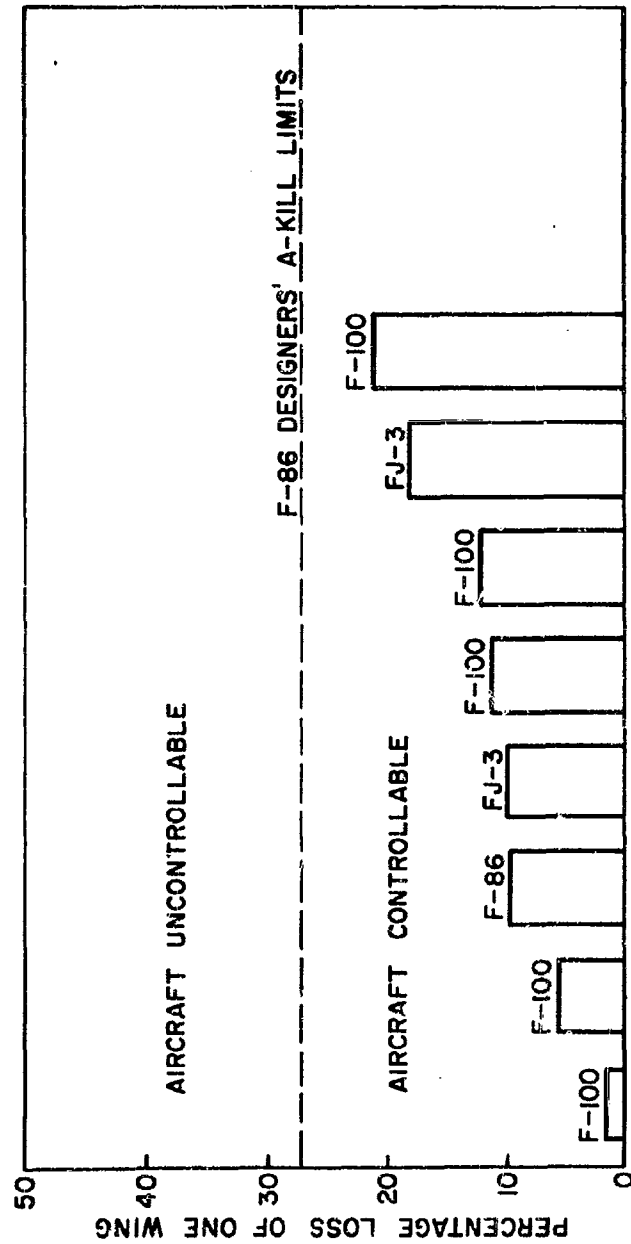


FIGURE 38. Percentage Loss of Wing Area of F-86, FJ-3, F-100 Aircraft Which Returned to Base Safely After Removal of Wing Tip and Adjoining Area

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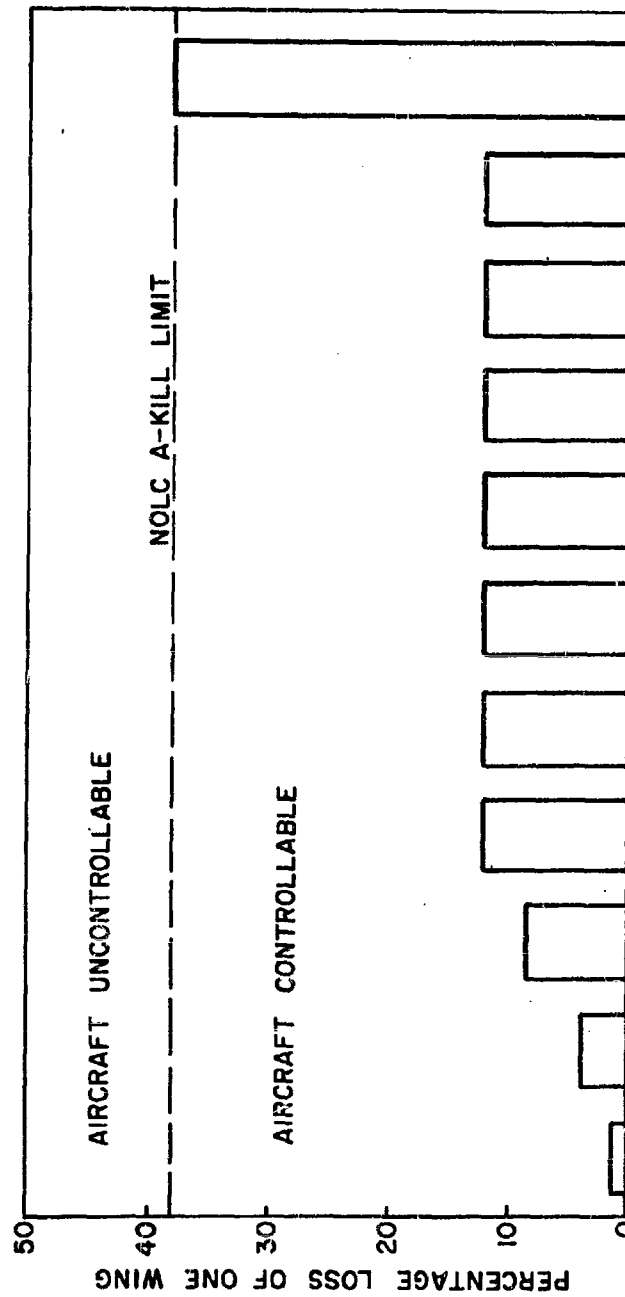
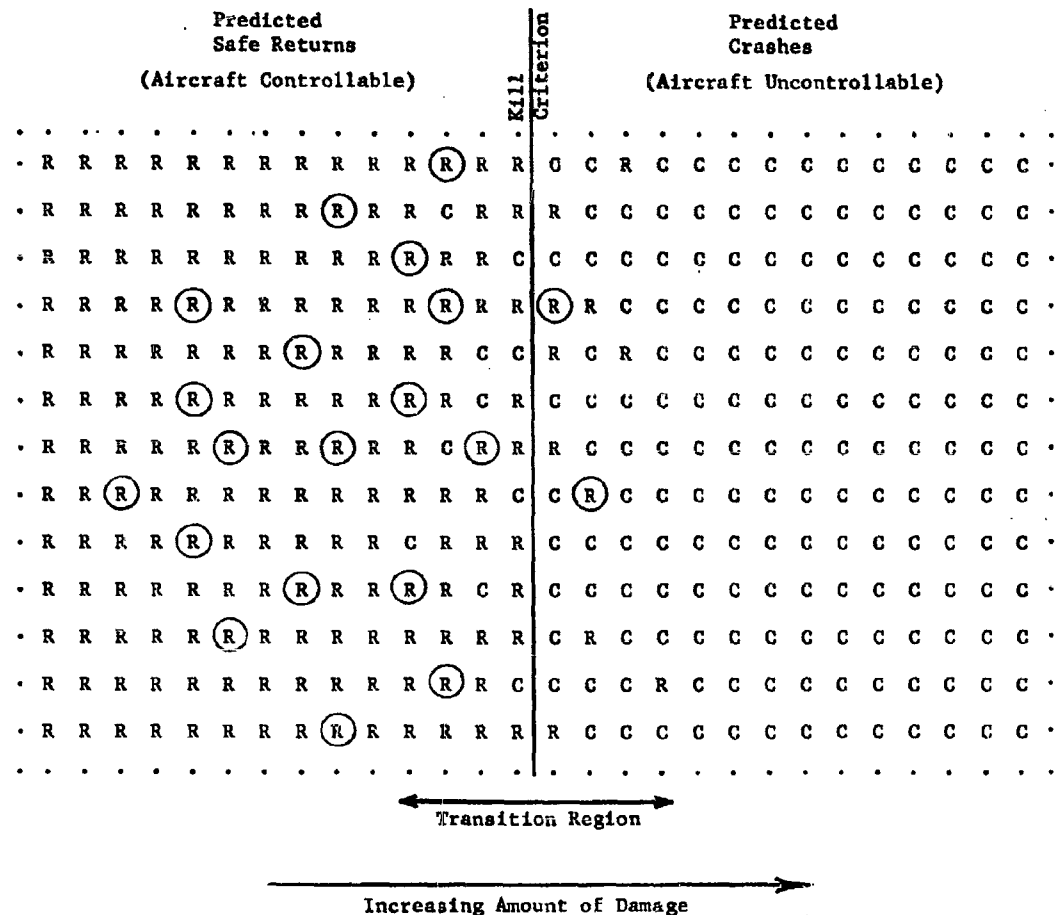


FIGURE 39. Percentage Loss of Wing Area of the F8U Aircraft That Remained Controllable After Accident

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C = Crashes that would occur in an infinite population
 R = Safe returns that would occur in an infinite population
 (R) = Safe returns included in the accident sample

FIGURE 40. Relation of a Typical Aircraft Designer's Kill Criterion to the Universe of Aircraft Damage Events (Occurring by Accident and by Enemy Action) and to the Corresponding Sample of Accidents Analyzed in This Report

NOLC Report 608

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IN REPLY REFER TO:
14 Jul 03

From: Commanding Officer
To: FOIA Program Manager, Defense Information Systems Agency, Attn: Ms. Kelly Akers
Subj: DECLASSIFICATION OF DOCUMENT AD 0352704 – EVALUATION OF
AIRCRAFT KILL CRITERIA BY ANALYSIS OF AIRCRAFT ACCIDENT
RECORDS

Ref: (a) Freedom of Information Act request by Mr. Kenneth P. Werrell dtd 4 Nov 02

1. In response to reference (a), the subject document has been reviewed by the Performance Assessment Directorate at Corona Division, Naval Surface Warfare Center. Department of the Navy Case Number 200300402 was assigned by your agency.
2. The document was published by the Naval Ordnance Lab, Corona, CA in August of 1964 and was originally classified CONFIDENTIAL. The subject matter in the document and the age of the document allow for declassification of the document and public release of the information.
3. Point of contact for this document review is Mr. Dennis Antonio, (909) 273-4893 or e-mail antoniodd@corona.navy.mil.


S. C. MILLER



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5720
Ser 03/0513
June 13, 2003

From: Commander, Naval Safety Center
To: Naval Surface Warfare Center, Corona Division
(Attn: CDR Taylor), P.O. Box 5000, Corona, CA
92878-5000

Subj: REFERRAL OF FOIA REQUEST FROM MR. KENNETH P. WERRELL

Ref: (a) PHONCON COMNAVSAFECEN (Code 03) LCDR Nancy Jones/
NAVSURFWARCEN Corona CDR Taylor on 9 Jun 03

Encl: (1) CNO ltr 5720 Ser N09B10C/3c507579 of 27 Feb 03
(w/encls)
(2) Mr. Werrell's ltr of 4 Nov 02
(3) COMNAVSAFECEN ltr 5720 Ser 03/0512 of 13 Jun 03

1. Per reference (a), enclosure (1) is forwarded for your review of the document entitled "Evaluation of Aircraft Kill Criteria by Analysis of Aircraft Accident Records" with regard to declassification and release under the Freedom of Information Act. If you determine that your command is the appropriate one to take action on this request, please provide a direct response to the requester identified in enclosure (2). If your command cannot take action on Mr. Werrell's request, please forward this package to the appropriate office for action. I have determined that the Naval Safety Center data utilized in the subject document is fully releasable. Enclosure (3) is provided for your information.

2. If you have any questions, you may call (757) 444-3520 DSN 564-3520 Ext 7047.


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